THE COAL-FIELDS

OF

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By the same Author.

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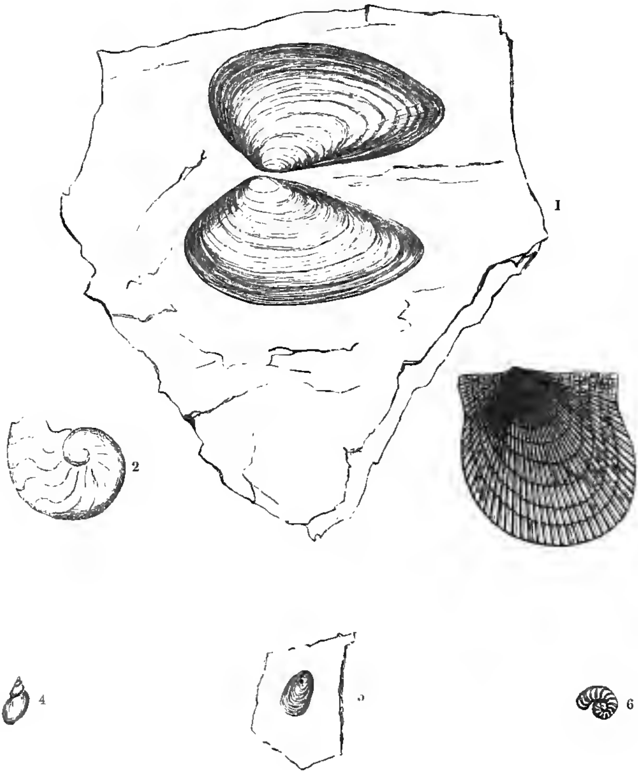
CHARACTERISTIC FOSSILS

OF THE COAL FORMATION.



1. ANTHRACOSIA ROBUSTA.
2. GONIATITES PARADOXICUS.
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THE COAL-FIELDS OF GREAT BRITAIN:

THEIR

HISTORY, STRUCTURE, AND RESOURCES.

WITH

NOTICES OF THE COAL-FIELDS OF OTHER PARTS OF THE WORLD.

BY

EDWARD HULL, B.A.,

OF THE GEOLOGICAL SURVEY OF GREAT BRITAIN; FELLOW OF THE GEOLOGICAL SOCIETY OF LONDON.

With Map and Illustrations.

SECOND EDITION, REVISED AND ENLARGED.

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TO

SIR RODERICK I. MURCHISON, D.C.L., F.R.S.

DIRECTOR-GENERAL OF THE GEOLOGICAL SURVEYS

OF THE UNITED KINGDOM,

This little Work

IS

GRATEFULLY AND AFFECTIONATELY INSCRIBED.

PREFACE.

The chief object of this treatise is to supply a want, which has been often expressed, of reliable information regarding the resources of our Coal-fields,—to what extent they have been already exhausted, and for what length of time the present supply can be maintained. Like many others, I was led to investigate the subject during the exciting discussions in Parliament upon the Commercial Treaty with France; and if any proof were needed of the diversity of opinion, and want of sound data upon the question of the exhaustibility of the British Coal-fields, it was abundantly afforded at that time.

It therefore appeared to me, that with the large means of information at my disposal—the Maps, Sections, and Memoirs of the Geological Survey, extending over two-thirds of the Coal-producing districts of England, the assistance of some of my colleagues of the Geological Survey, of several of Her Majesty's Inspectors of Collieries, and of gentlemen of experience scattered throughout the country—much more definite results might be arrived at than had hitherto been published. I may also be allowed to add, that my own personal knowledge of the Coal-fields of the Central and Northern Counties is not inconsiderable, and that I have not neglected any published sources of information which were accessible.

In order to make the work more complete, several introductory chapters on the nature of the Carboniferous rocks—the character of the vegetation of the Coal-period—and the formation of Coal itself—have been introduced. Also, for purposes of comparison, I have added short sketches of the nature and extent of Coal-fields of other parts of the world, drawn from the most authentic sources.

Conscious of many defects, I am fain to hope that these pages will be found to accomplish faithfully the great object designed,—to give the public an answer to the oft-repeated question, "How long will our Coal-fields last?"

PREFACE TO THE SECOND EDITION.

In this edition I have made many additions, and, it is hoped, improvements. With the assistance of my colleagues, Messrs. Geikie and Howell, I have been able to include the mineral resources of Scotland with those of England and Wales. I have also added sections of the Coal-series of South Wales and of Somersetshire, for which I am indebted to Mr. Etheridge.

The production of the various Coal-fields has been modified in accordance with the "Mineral Statistics" for 1859, collected by Mr. R. Hunt; and to this gentleman I beg to express my acknowledgments for assistance in reference to the statistical part of the work.

A map showing the area of the productive Coal-fields, and the probable depth and extent of the Coal-formation below the newer strata, is now furnished, besides an additional horizontal section of the formations in Lancashire.

Chapters on the "Duration of our Coal Supply," and on "The Physical Geography of the Carboniferous period of Britain," are added; and I venture to express a hope that the work will now be found what I have long purposed to make it—a safe and complete Handbook to the British Coal-fields.

The notices of the Coal-bearing strata in other parts of the globe have been considerably enlarged.

Since these pages were in type Mr. Vivian's *Lecture on Coal, &c.*, has been placed in my hands. In this very lucid discourse the author defends, on grounds to which I allow great weight, the statements he had made before Parliament on the resources of the South Wales Coal-field. I feel indebted to Mr. Vivian for his severe, though friendly, criticism of my estimate of these same resources. After a careful consideration of the facts and observations recorded by Mr. Vivian, I am inclined to believe that I may have under-estimated the available supply from this great storehouse, as I was not aware of the full effect of the "central upheave" in placing the beds of thick coal within reach over so large an area. I shall look forward to making a personal acquaintance with a region, only, as yet, known to me by maps, sections, and books; and should this little work continue in favour with the public, the result may be inserted in a future edition.

As Mr. Vivian places the duration of this Coal-field at 5,000 years, and myself at nearly 2,000 years, there will be abundance of time for arriving at an amicable conclusion on the subject before the course of events shall have verified or falsified either of our calculations.

The woodcut illustrations have been engraved under the superintendence of Mr. S. J. Mackie, Editor of the "Geologist," with the exception of one by Mr. Lees.

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INTRODUCTION.

THE question of the exhaustibility of our coal-fields is a highly complicated one; for while an actual exhaustion is beyond all possibility, a practical and sensible failure in the supply of coal is not only possible, but certain in course of time.

The debates in Parliament have brought into prominence a subject which, from the days of Sir Robert Peel's premiership, has more or less engaged the serious consideration of public men. The opinion of the learned Dr. Buckland regarding the probable exhaustion of the British coal-fields is known to have influenced the measures of that statesman; and in the late debates on the Commercial Treaty with France, the statistical information produced by Mr. Vivian is believed to have materially influenced our legislature in favour of the measures of Government.

I refer to this debate as illustrating how diversified are the opinions entertained on this subject by some of the most eminent politicians, and which are only a reflex of those of the public generally.

The want of accurate and reliable information on this subject is much felt. If legislation is to be based upon the question whether this country can, without irretrievable damage to its resources, admit of the unrestrained export of coal, it is surely of first importance that there should be accurate data to go upon; and though I admit that the question is not one which can be determined with mathematical precision, yet we may at least arrive at sufficiently approximate results, by a combination of the evidence obtained from each individual coal-field.

The first evidence of a decreasing supply will be a sensible rise in the price of coal: but, through the agency of railways, this will not become general until the resources of all the coal-fields shall have become developed to their full capabilities, because, where the supply shortens in one district, a corresponding impetus will be given to others now only partially opened up.

Two illustrations may be mentioned.—Many of us may live to see the southern half of the South Staffordshire coal-field exhausted, or nearly so; but while this consummation is approaching, the northern half of the same great coal-tract is far from being opened up to the extent of which it is capable. The exhaustion of the southern portion is already telling upon the northern.

The interesting and instructive coal-field of Coalbrook Dale, in Shropshire, is fast approaching extinction as a coal-producing district. There is probably not more coal than will last for a quarter of a century, at the present rate of consumption. But there is a neighbouring coal-field, that of Denbighshire, capable of producing about five times its present supply. Between Brymbo collieries on the north and those of Ruabon on the south, there is a large area of virgin ground, well stored with coal, and scarcely disturbed. Other examples will be found in the following pages.

In speaking of the exhaustion of a coal-field, I do not use the term in an absolute sense. There will always be bands of coal, besides leavings, in the coal-mines, sufficient to afford a small supply to the immediate neighbourhood for domestic purposes. A coal-field may be said to be exhausted, when it is necessary to import largely from neighbouring districts for manufacturing and more general purposes. From various causes, large quantities of coal have been left in old workings, much of which it will be impossible to recover. Thus in the Leicestershire coal-field, where a bountiful Nature has left a "12-foot" coal-seam, only one half has actually been raised—the "upper," or "nether" portions being less valuable than the remainder in various parts of the field.

I have already said, that the British coal-fields can never be utterly exhausted. This is strictly true. Even disregarding the coal-beds which lie concealed beneath formations newer than those of the Carboniferous period, there are, in some districts, coal-seams which are buried 6000, 8000, and perhaps 12,000 feet beneath the surface, and which can never be reached. I refer particularly to the great coal-basin of South Wales, which, as Mr. Vivian has shown, is capable of supplying the whole of England with coal;—but for, I believe, a far shorter period than Mr. Vivian estimates it. In a future page I shall enter in greater detail into this subject; and here content myself with stating the broad fact of the enormous depth of some of the coal-beds in that basin, on the authority of the late Sir H. T. de la Beche, and Sir W. Logan, through whose energy the magnificent geological survey of this district is now in the hands of the public. Now, without assigning in this place any theoretical limit to the depth at which coal may be worked, few will be disposed to deny that coal-seams at these depths might as well be buried beneath the waters of the Atlantic for all the probability there is of their ever being rendered available.

There are other districts, principally in the Midland counties, where the coal strata, though not themselves of any very great thickness, dip under higher formations till they reach vast depths. For instance, there is no reason to doubt that coal underlies the plain of Cheshire, between the coal-fields of Lancashire on the north, Staffordshire on the east, and Flintshire on the west; yet in order to reach the highest workable coal-seam at Northwich, it would be necessary to carry the shaft which reaches the great salt rock at least 4000 feet deeper than at present.

There are, however, very large districts in Staffordshire, Leicestershire, and Warwickshire, overspread by formations belonging to the Permian and Triassic systems, where coal may be reached at depths within 3000 or 4000 feet. In the north-eastern counties of Durham, Yorkshire, and Notts, there are also vast stores of fuel within reach, but overspread by formations belonging to the age of the Permian and Trias. In Durham, the Magnesian Limestone, which attains there a thickness of 500 feet, has for several years been penetrated in various places down to the underlying coal; and the same formation, in its southerly extension into Yorkshire and Nottinghamshire, bids fair to become a coal-producing district of large extent and capacity.* One of the deepest mines in England, that of Shireoak, near Worksop, belonging to the Duke of Newcastle, is situated on the Magnesian Limestone; and after obstacles of no ordinary kind had been triumphantly surmounted, was carried down into the long-wished-for coal-seam, at a depth of 510 yards.

The depth of many coal-shafts in the north of England is very great. At Inee, near Wigan, the "Cannel" seam is reached by means of two "lifts," at a depth of 600 yards.† Pendleton colliery, near Manchester, is 536 yards deep; that of Dukenfield, Cheshire, 686 yards. The Monkwearmouth pit, near Sunderland, has a depth of 530 yards: and collieries with shafts between 400 and 500 yards are not uncommon in the coal-fields of Lancashire, Yorkshire, and Durham.

Notwithstanding, however, all that art and industry can invent to facilitate mining at great depths,—notwithstanding the increased powers of the machinery and improvements in ventilation, the employment of flat wire ropes, the substitution of steel for wrought

* See Map. † Appendix A., p. 264.

iron, and the use of two or more "lifts" or stages, at intervals from the bottom of the mine,—we must ultimately reach a depth at which the temperature will be so high as to prohibit inexorably mining operations. What that depth may be I shall discuss in a future chapter: in the meanwhile, let us review briefly the progressive course of coal-mining from its infancy to the present time.

PART I.

CHAPTER I.

FRAGMENTS IN THE HISTORY OF COAL-MINING.

THE first attempts at coal-mining are enveloped in obscurity; but even from the chronicles of those days, when nothing was thought worth recording save the accession of a prince, the feuds of neighbouring states, and the details of a battle, enough has been incidentally noted to enable us to trace back the art of coal-mining to very early times.

Its beginning was sufficiently humble. Its nature and properties being little understood, there was nothing in the outcropping of a black substance along the sides of a hill or the banks of a brook to arrest attention; but it is not improbable that from the earliest periods—at any rate from the time in which implements and weapons of metal replaced those of flint—fossil fuel may have been employed for smelting purposes. Fortunately on this point we are not left altogether to conjecture, as I shall have occasion to show presently.

Like many other treasures of Nature, the use of coal did not become general until its necessity had become paramount. While in the days of Anglo-Saxon and Anglo-Norman art, and those which immediately succeeded, the plains of England were overspread with almost continuous forests, growing, as in Staffordshire and Lancashire, frequently in dense luxuriance over the mineralized forests of geologic ages, and while these forests readily yielded an abundance of fuel for all the purposes of the times, it was both unnecessary and improbable that the labour and risk of mining should become general. The precious mineral was reserved for a generation to whose very existence it is almost a necessity; a generation that, without its aid, could scarcely (as far as we can see) have arrived at the position in art, industry, and navigation, which it has attained in the nineteenth century.

I must now ask my reader to accompany me through a few of those details in the history of coal-mining which I have been able to collect. I do not profess to have exhausted the subject; for the more I have entered into it, the more am I satisfied that much remains to reward the industry of the antiquarian. The notices we find are like stepping-stones for crossing a river; sometimes they are large, copious, and closely placed, at other times wide apart, so that we have to make a leap perhaps over several centuries at a time; but I have no doubt further researches will enable us to add to the numbers of the stone-steps, so as to lessen the gaps, if we cannot hope to make a continuous road from the shore of the past to that on which we stand.

It is scarcely necessary to observe, that the frequent references to coal in the Sacred Scriptures cannot be considered as pointing to that mineral as at present understood. The original word doubtless means charcoal, which, like the Latin term, may be employed to designate fuel of both kinds. I should not, however, be so confident that coal itself was not sometimes intended, if there was any certainty of its existence as a product of the Holy Land or Arabia; but as far as I am aware there is no mention by any traveller of this mineral occurring amongst the Nummulite limestones, the red sandstones, or basaltic lava-floes of these countries. Its nearest position to Palestine is perhaps on the shores of the Black Sea and Bosphorus.

Period before Christ.—Theophrastus, a Greek author who lived about 238 years before the Christian era, describes, in brief but determinate language, the nature, uses, and source of coal. It is a sufficient proof of this mineral being intended, that the description applies accurately to it, and to no other. He says: "They call those fossil substances (λιθὺς ἄνθρακας) anthracite (or coal), and when they are broken up for use, are of an earthy character (γεώδεις); nevertheless they inflame and burn even like charcoal (καθάπερ οἱ ἄνθρακης), and are used by the smiths." He adds, that the coal is found along with amber and other substances in Liguria, and in Elis on the road to Olympias over the mountains.*

* It is scarcely necessary to give the original passage of which the above is a literal translation, and varies only slightly from that of Mr. John Hill, who edited an edition of the "History of Stones" in 1746. Pennant also notices the passage, and does not hesitate to refer it to coal.

There are several other passages in the same work descriptive of combustible minerals, but described in such vague language that it is impossible to identify them. The passage above quoted is, it appears to me, sufficient, and its value would scarcely be strengthened by the addition of a score of others which might be applied to as many different substances.*

The passage in Pliny† is of little service, though sometimes quoted as referring to coal. Speaking of a certain earth (Chia terra), he merely says of it that "Bitumini simillima est ampelitis." Theophrastus, in speaking of this stone, says: "There is a certain earth in Cilicia, which is heated and becomes glutinous. With this they smear the vines (as a protection) against worms." Strabo reiterates the above description—in all probability only quoting it.

Ancient Britons.—It might scarcely be credited, were it not established on incontestable evidence, that there were coal mines amongst those savage clans and roving barbarians, such as we are generally taught to consider the Britons of prehistoric times. The discovery of a flint-axe stuck into a bed of coal exposed to day in Monmouthshire is a fact which, like the occurrence of a solitary fragment of a plant in a very ancient rock, proves a great deal more than appears at first sight. If we accept the theory, that flint weapons were the earliest representation of three stages of civilization, of which bronze implements were the second, and iron implements

* See also the same author in "Περι Λιθων." Art. 49.

† Nat. Hist., lib. xxxv. 16.

the third, this discovery carries us back to a very early period, antecedent to the invasion of the Romans.

I am persuaded this is not a solitary case, though I know of none strictly parallel. Near Stanley in Derbyshire, some years since, while some miners were engaged in driving a heading through the "Kilburn coal," they broke into some very old excavations, in which they found axes or picks formed out of solid oak. The implements were entirely destitute of metal, and were cut out from one solid piece of timber. It is hard to imagine the use of such an instrument where iron was known; while it is also difficult to conjecture how an axe of this kind could have been formed without the assistance of iron. The neighbourhood of these old workings abounds in iron-ore, several beds of clay iron-stone occurring both above and below the Kilburn coal. If the use of these ores had been known, it is scarcely to be supposed that the miners would have made use of picks formed entirely of oak. Implements which appear to have belonged to an equally early period are stated to have been found in old coal-workings near Ashby de la Zouch, consisting of stone hammer-heads, wedges of flint, as also wheels of solid wood.*

Whittaker states that there is indubitable evidence from the discoveries at Castle-Field, near Manchester, that the Britons had made use of coal in that neighbourhood. He refers to the existence of fragments of coal in the beds of sand *under* the Roman road, and in a pit a few feet deep contiguous thereto.† But I very much

* Mammat's "Geological Facts."

† "History of Manchester," vol. i., p. 302 (1771).

doubt the value of such evidence. Those acquainted with the Drift, or Post-pliocene deposits of Lancashire and Cheshire, know that drifted fragments of coal are extremely plentiful therein; and there is strong probability that those upon which he dilates so enthusiastically were carried to their beds in the sand long even before the time of the *Aborigines* of Britain; and not by the hand of man.

Romans in Britain.—That the Romans were acquainted with the use of coal during their occupation of Britain is highly probable, both from what we know of the character of the race and from circumstantial evidence. They had stations in many places close to the out-crop of valuable coal-seams, and cinders have been found amongst the ruins of Roman towns and villas. I may here mention a case which has always appeared to me as probably referable to this period. Wigan in Lancashire was a Roman station. Not far to the north of that town, a bed of coal—one of the most valuable in Lancashire, and known as the "Arley Mine,"—out-crops along the banks of the river Douglas. Not long since, while driving a tunnel to divert the course of the river, this coal-seam of 6 feet in thickness was found to have been mined in a manner hitherto altogether unknown. It was found to have been excavated into a series of polygonal chambers, with vertical walls opening into each other by short passages, and on the whole presenting on a ground-plan something of the appearance of a honeycomb. The chambers were stated to be regular both in size and form over an area of at least 100 yards in one direction, and were altogether different from anything within the experience of the miners of the district. Local tradition ascribed these excavations to the Danes, though I could not discover upon what grounds. We should probably be nearer the truth in assigning them to the Romans during their sojourn in these parts. There is something in the symmetrical arrangement and regularity of the works peculiarly Roman, reminding one of their tesselated pavements, or the ground plans of their baths and villas, in which symmetry of form appears to be the guiding spirit. It would, however, have been more satisfactory had the evidence rested on the discovery of works of art within the excavations. But it is time to return from this digression to the more sure word of history.

If Whittaker, the historian of Manchester, has been unsuccessful, in my opinion at least, in establishing upon satisfactory evidence the use of coal by the Ancient Britons, he has been more fortunate in showing that fossil fuel from the Lancashire coal-field was burnt by their successors, the Romans. Castle-Field—an original settlement of the Britons—was afterwards possessed by the Romans under the name of Mancunium. In the course of time it has slightly changed its name, and developed into the metropolis of the northern counties of England. Amongst other Roman remains turned up about a century ago, cinders and scoriæ were discovered in several places, as well as the "actual refuse of some considerable coal-fire."*

The same author also relates, that in the West Riding

* "History of Manchester," vol. i., p. 301.

of Yorkshire, near North Brierley, a quantity of Roman coins, the very best indices for dates, were found "carefully reposited" amid many beds of coal-cinders heaped up in the adjacent fields.*

Horseley, speaking of some inscriptions found at Benwell, near Newcastle-upon-Tyne, the Condercum of the Romans, states that there was "a coalry not far from that place, which is judged by those best skilled in such affairs to have been wrought by the Romans."† Wallis also states, that in digging some of the foundations of the city of Magna, or Caervorran, in Northumberland, in 1762, cinders, in all respects similar to those derived from coal, were found in considerable quantity.‡

Mr. T. J. Taylor, in an article on the "Archæology of the Coal-trade,"§ also refers to the discovery of coal-cinders as part of the relics of the Roman stations of the neighbourhood, notices of which are contained in the records of the Antiquarian Society of that town.

Similar evidences of the use of coal by the Romans are stated to have been discovered at Lanchester, and Elchester in the county of Durham.

Assuming from the general consideration of the case that coal was not unknown to the Romans—though they do not appear to have invented a name for it while in Britain, and it was probably used more from curiosity than from necessity—we enter upon the Anglo-Saxon

* "History of Manchester," vol. i. p. 303.

† "Britannia Romana."

‡ "Hist. of Northumberland."

§ Proc. Archæol. Institute of Newcastle, vol. i., p. 151.

period, in which there is documentary evidence of the use of pit-coal for domestic purposes.

Anglo-Saxon Period.—Britton, in his description of Peterborough Cathedral, renders into modern English the following paragraph taken from the Saxon Chronicle of the Abbey of Peterborough:—"About this time (A.D. 852) the Abbot Ceolred let to hand the land of Sempringham to Wulfred, who was to send each year to the monastery '60 loads of wood, 12 loads of coal, 6 loads of peat, 2 tuns full of fine ale, 2 neats' carcases, 600 loaves, and 10 kilderkins of Welsh ale, 1 horse also each year, and 30 shillings, and one night's entertainment.'"* How Wulfred was to send the provident abbot "one night's entertainment" it is not necessary for our purpose to inquire; but this statement of the chronicler is highly valuable as establishing the fact that coal was at this early period an article of household consumption. It may also have been made use of by the monks, who were the artificers and craftsmen of their times, in the manufacture of metal-work for the churches and monasteries.

In connection with this period, it is matter for dis cussion whether our term "coal," which is evidently identical with the German "kohle," has been derived from our Saxon ancestors, or whether, on the other hand, the Germans have derived it from us. It is probable the term was in general use before the invasion of the Normans, otherwise the French or Latin name would in all probability have been adopted. The Saxon

* Cathedral Antiquities," vol. v.

name *col* (now coal) appears to have superseded the old British name *glo*, and if introduced into Britain at the colonization of the country by the German tribes, it is in favour of the supposition, that the art of coal-mining was practised in Europe during the first centuries of the Christian era.*

If we have derived the term "coal" from our Saxon forefathers, from whom did they derive it? Now there

* I have been favoured with the following note on the derivation of the word Coal by my relative, Mr. William J. Leacock, which I give entire:—

"There are only five copies extant of the original Saxon Chronicle, of which four are in the British Museum. The original Anglo-Saxon words used in reference to Wulfred's rent to the Abbot of Peterborough are—'anð tpælf poðup gpæfan,' *i. e.*, in modern English letters 'aud twælf rothur græfan.' Bosworth, in his A. S. Dictionary, gives under Græfe, an; m. Coal: Carbo fossilis. Chr. 852: (*i.e.*, the above passage), so that this seems to be the only passage in which the term is used. No derivation is given, and I can find no parallel in the Dutch or German; but perhaps as we have Anglo-Saxon 'Greaf or Graf;' Dutch the same, German 'Grab,' and so through all the northern languages, for a trench or 'grave,' it simply means the 'dug-up' earth.

"I find, however, in the A. S. Dictionary, 'Col. plur. cola, colu. [Ters. *i.e.* Teiresia *hôal*, Dutch hool.] Coal, carbo: with reference to Psalm 17, 10, 13 and 139, 11, *i. e.*, the Psalms, by Spelman, London, 1640, the division of the Vulgate being used.'

"There is also, Gled, Gloed, plur.: with many parallels in the northern languages, meaning a burning coal, coal, fire; carbo. used in Ps. 17, 14, &c.

"In Somers' A. S. Dict. the word *Græfa* is not to be found; but *Græf*, which means a grove as well as a grave. He gives 'Col. carbo. a coal to burn;' but says nothing about derivation.

"The following is Richardson's etymological account of the word 'Coal.' He says it is 'of unsettled etymology. A. S. *Col*: German and Dutch *Kohle*: Swedish *Kol.*' Vossius derives from the Greek, χαλεος pro χηλεος, Ignis epitheton. Wachter from χηλοειν, comburere. Ure seems to decide for the Swedish *Quilla*, Westro-Goth *Kylla*, accendere ignem (to kindle a fire).

are certain German words which have been derived from the Greek, and amongst these the word "kirche," or church, from κυριακή, forms a notable example.* Recollecting how coal of various kinds and ages is distributed over all parts of Europe, it is just possible that the German word "kohle" may be derived from the Greek κοιλος, "hollow," as descriptive of a mineral which it was customary to hollow out of the earth.

An American author has remarked that language is "fossil poetry." May there not lie concealed under our blunt Saxon word a germ of poetic thought? Robert Stephenson was as truly a poet as a philosopher when he said that the heat of burning coal is but the liberation of those rays of the sun which have been locked up in the dark chambers of the rocks since the time that our great luminary shone down on the primæval forests. Now we cannot but recollect that the Latin word for heaven, "cœlum," is derived from κοιλος, and thus there is a curious, but only accidental similarity between the word "coal" and the source of "every good and perfect gift." May we not carry out this fancy a step further, and, as believers in an eternal Providence, acknowledge that the mineral is a heaven-born gift to man?

Anglo-Norman Period.—It is matter for surprise, as well as regret, that in the Great Survey of England carried out by William the Conqueror, and recorded in that most matter-of-fact book, the Domesday Book, no instructions were delivered to the commissioners for inquiring into the extent and value of the mineral pro-

* See Trench, "On the Study of Words."

perty of the central and northern counties. They appear to have confined their investigations entirely to the extent, rights, and ownership of the surface land, together with the classification of the inhabitants ; but throughout the counties of York, Lancashire, Derby, and Nottingham, abounding in coal and other minerals, no mention whatever is made of these latter sources of wealth.

In order to test this point, I turned to the page relating to Chellaston in Derbyshire, where a most valuable bed of gypsum, or alabaster, underlies a large extent of surface at no great depth, and crops out as a solid bed ten or twelve feet in thickness. This mineral (which we know to have been worked centuries ago) could not even at that time have been undiscovered, for the ploughshare scrapes its surface in many places, and it may well be supposed to have been a source of wealth to the owner. Yet there is no mention made of the mineral value of the property in the "Dom Boc." Even the lead mines of Derbyshire, known to have been worked by the Romans, are unnoticed, and therefore we need not be surprised that coal receives no mention.

However, in the Boldon Book, containing the census of portions of the northern counties, and published in the reign of Henry II., we find at least two references to coal. It is here stated that the carpenter of Vernouth, now Wearmouth, who is an old man, holds twelve acres for life for making carts and harrows for the tenants, and that the smith (Faber) has an equal quantity of land for the iron-work of the carts, and finds the requisite coal (carbones invenit). I think this passage cannot be considered as referring to charcoal obtained from wood. In this sense the verb *invenit* would be inapplicable, but is not so when used in reference to a kind of fuel which requires discovery. The census of Seggefeeld follows very closely upon that of Vernouth, and here also the smith of the village is said to find the coal for his forge.* What a curious insight into the customs of those times is afforded by these passages! In the small communities of Vernouth and Seggefeeld, the carpenter and smith are bound to keep in repair, and probably provide, the implements of agriculture for the farmers in consideration of a certain extent of land, money being probably not in general use amongst the villagers of that period.

The Latins had an old proverb, quoted amongst many others by Phædrus, "Carbonem, ut aiunt, pro thesauro invenimus." This has been considered as referring to charcoal; but it appears to me under this supposition to lose all its significancy. The same objection may be urged to this interpretation as has been stated in reference to the passage in the Boldon Book—for the same expression is used in both. "Finding" a lump of coal instead of treasure has some meaning in it, but the finding of a piece of charcoal under similar circumstances appears utterly unintelligible.

* Inquisitio dē consuetudinis, et reditibus totius Ep'atus Dunelmensis, Anno 1183. The difficulty of reading this work, which, like the Domesday Book, is full of abbreviations and elliptical expressions, is great; as examples I quote the passages above alluded to:—"Vernouth. Faber xii. acr' ꝑ ferramentꝭ caruc' & carbones qm' invenit." "Faber, 1 bovat. ꝑ ferrametꝭ caruc'. que fac'. & carbon' invenit.

The year 1259 is memorable in the annals of coal-mining. Hitherto the mineral had not been recognized by authority or in any public document; but in that year King Henry III. granted a charter to the freemen of Newcastle-on-Tyne for liberty to dig coals. Under the term "sea-coal" a considerable export trade was established with London, and it speedily became an article of consumption amongst the various manufacturers of the metropolis. But its popularity was short-lived. An impression became general that the smoke arising therefrom contaminated the atmosphere, and was injurious to the public health. Years of experience has proved the fallacy of the imputation; but in 1306 the outcry became so general that the Lords and Commons in Parliament assembled presented a petition to King Edward I., who issued a proclamation forbidding the use of the offending fuel, and authorizing the destruction of the furnaces and kilns of all who should persist in using it. This was the year before the monarch's death, and the year which saw the overthrow of his life-long attempts upon the throne of Scotland, through the intrepidity of Robert the Bruce. But the proclamation against coal was as abortive as the endeavour to conquer the patriotism of the Scots. Prejudice gradually gave way as the value of the fossil fuel became better known, and from that time downwards its use became more extended; and it is very probable that throughout the 14th and 15th centuries coal was extracted near the outcrop of the beds over most, if not all, of the coal-fields of Britain and Ireland. Historical records are still extant from which we learn that collieries were opened during the 14th century in various parts of Yorkshire, Durham, and Northumberland.

The anonymous author of the "History of Fossil Fuel," observes in reference to the 13th century: "The strongest and most unequivocal proof that this species of fuel (coal) was in use amongst us during the reign of Henry the Third is to be found in an inquisition preserved among the additions to Matthew Paris's History, of the date of 1245. Here we find it called *carbo maris*, or *sea-coal*—an appellation retained through succeeding centuries—with express mention of making pits to win it, and of the wages of the colliers that wrought in them."

Leland* has the following passage: "The vaynes of the se-coles ly sometyme upon clines of the se, as round about Coquet Island, and other shores; and they, as some will, be properly called se-coles; but they be not so good as the coles that are digged in the inner part of the lande."

We have numerous references to the use of coal in the 14th century. Surtees, in his "History of Durham," mentions a coal-mine, in connection with the vicarage of Merrington, in the county of Durham, in 1343; as also the notice of the sinking of pits at Ferryhill, in the same county.

Mr. Taylor, in the Memoir already alluded to, says: "We have thus a tolerably clear historical account of the Newcastle coal-mining and its adjuncts in the 14th century. We have seen that collieries were then

* "Itinerary," vol. viii.

certainly opened over a considerable extent of our coal-field, since they were being worked in the districts of Newcastle, Elswick, Birtley, Winlaton, Merrington, and Lanchester. To these may be added coal-mines in Bedlingtonshire, the produce of which was probably shipped in the river Blyth (Northumberland), for we find the Bishop of Durham in 1368 appointing a supervisor of the mines of that district. That coals were also shipped from Sunderland in the same century we have proof in the rolls of Whitby Abbey in 1395, when 13 shillings and 4 pence were paid to William Rede of Sunderland for four chaldrons of coal."*

The use of coal in London was resumed within a few years after its prohibition by the king in 1306; as we find in the "Petitiones in Parliamento," in 1321-2, a claim made for ten shillings, on account of coal which had been ordered by the clerk of the palace, but the payment for which had been neglected.

Amongst other incidental notices of coal in the 14th century is that of Æneas Sylvius, afterwards Pius II. On his visit to Scotland he had opportunities of witnessing the poor receiving as alms at the gates of the monasteries pieces of coal, "which," he states, "they burn in place of wood, of which their country is destitute."†

Coal-mines are also mentioned in the abbey leases of this century. Tynemouth priory had a colliery at Elswick in 1330, let at a yearly rental of six marks, to be paid so soon as the tenant commenced working the

* Proc. Archæol. Inst. Newcastle, vol. i.
† Ænei Sylvii Opera, p. 443. (See Appendix.)

coal. The rent of another new colliery in 1334 is stipulated at 40*s.* yearly.*

In the reign of Queen Elizabeth the coal-trade flourished greatly, and continued to be regarded as an important source, not only of local but of national revenue by succeeding monarchs. In the reign of Charles I. the trade was burdened by excessive taxation and grievous monopolies. After the capture of Newcastle by the Scottish army, the House of Commons undertook the regulation of the coal trade, by which step, supplies were shipped into the port of London for the use of the poor, coals having previously risen to the price of 4*l.* per chaldron.†

The difficulties under which mining operations were carried on before the invention of the steam-engine, and more particularly of the "Davy lamp," must have been very great. An anonymous writer in the "Builder" states, that in many mines the only alternative the mediæval miner had to pitch darkness was the phosphorescent gleam from dried fish.‡ Those who wish to understand the art of mining as it was carried on at this period will find their curiosity amply gratified by turning over the pages of Agricola's treatise on mining. This author, who wrote in the middle of the 16th century, has illustrated the various processes by a profusion of quaint drawings on a large scale. The horse-gin, which survives to the present day in many districts, was the engine chiefly employed both for lifting the coal, and for getting rid of the water. This latter object was

* Proc. Arch. Inst. Newcastle, vol. i.

† "Hist. Fos. Fuel," p. 316.

‡ See Appendix E., p. 235.

also sometimes effected by means of pumps turned by windmills, or through tunnels driven with great labour to an outlet at a lower level.

Pennant, in his account of the collieries of Flintshire, states that there is documentary evidence to show that the coal-seams of Mostyn were worked in the time of Edward I.; and in the 17th century, Dublin and the eastern parts of Ireland were supplied from this district.*

In the year 1600, or thereabouts, coal was worked at Bedworth in Warwickshire, as we learn from Camden, who describes the process, and says that the miners assured him that large *toads* had been found in the solid coal.† In this century also the mineral treasures of the bishoprick of Durham were well known; and early in the 17th century the cannel-coal of Lancashire was used, not only by the poor for candles, but was manufactured into various articles of ornament or use. Camden, in speaking of the discovery of this most valuable description of coal at Haigh, near Wigan, says: "This neighbourhood abounds with that fine species of coal called *canal* or *candle*. It is curious and valuable, and besides yielding a clear flame when burnt, and therefore used by the poor as candles, is wrought into candlesticks, plates, boxes, &c, and takes a fine polish like black marble."‡

* "Tour in Wales," vol. i. (1784).

† Camden's "Britannia." Gough's edit., vol. ii., p. 464. This belief amongst miners of the existence of live toads in coal is very extraordinary, and is almost coextensive with the art. I was assured by a miner in Lancashire, near Ormskirk, that a toad had been brought up in a piece of coal from a mine thirty-six yards in depth, which immediately revived on reaching the surface!

‡ "Britannia," vol. iii., p. 390.

That coal was worked in Ireland at least as early as the beginning of the 16th century, and possibly much earlier, may be inferred from the following account given by Hamilton in his "Letters on the Coast of Antrim." He relates that in 1770 the miners of Ballycastle, in pushing forward an adit towards a bed of coal in an unexplored part of the coal-field, unexpectedly broke into a narrow passage, which proved to have been carried several hundred yards to a bed of coal, and then branched off into chambers. Pillars had been left at proper distances. Some remains of tools and baskets were found, which speedily crumbled to pieces. Those who are aware how the accounts of mining operations are handed down through several generations will readily admit that the old works here mentioned, and of which all local tradition had been lost, must have been carried on at least a century and a half before the period when they were afterwards discovered, which would throw back the date nearly to the beginning of the 16th century.

In Scotland the coal-seams of the Lothians and Fifeshire were probably worked at a very early period. Agricola, and after him Camden, mentions that in his time there existed in the latter county old coal-pits, filled with water, and surrounded by mounds of refuse called *coal-heughs;* and he adds that "many of the beds of coal have been on fire for centuries, and the heat still continues to melt the snow on the surface."* These old coal-works would appear to have been at least as old as the 15th century.

* Camden's "Britannia," vol. iv., p. 114. This elaborate work was published in 1607.

Campbell, in his "Political Survey of Britain," published in 1774,* gives us some interesting details of the coal-trade in his time. He states, that although coal was employed in manufactures for several hundred years, it did not come into general use till the reign of Charles I., and was then sold for seventeen shillings a chaldron. In 1670, about 200,000 chaldrons, and at the Revolution (1690) upwards of 300,000, and in the reign of George III. (1760) double that quantity, was annually consumed in Britain. He adds: "There is little room to be alarmed from the apprehension of their (the mines) being exhausted, as the present works are capable of supplying us for a long series of years, and there are many other mines ready to be opened when any of these shall fail,"—a piece of information which must have been exceedingly consolatory to those of the last generation, but not so assuring to us who have lived to see the annual consumption of nearly 70 millions of tons.

Sir John Clerk, in a letter to a friend, written in 1739, gives an interesting account of the collieries of Whitehaven.† The coal-beds even at that time were worked far under the sea, so that, as the writer observes, Sir James's riches in part swim over his head, for ships pass daily above the very ground where his colliers work. The coals were drawn up by an engine turned by two horses, which went their circuits at full trot every eight hours, and three changes were employed

* Vol. ii., p. 30.

† These collieries belonged to Sir James Lowther, who was held in high estimation by the people, his death being looked forward to as a public calamity. Camden, vol. iii., p. 434. Gough's edit.

every twenty-four hours. Sir John Clerk then proceeds to give a long and minute account of the quantity of coal raised, its cost, and how much the proprietor cleared after paying all expenses, which amounted to the very moderate figure of 600*l.* a year, or thereabout. The writer also states that the upper coal-seams were much exhausted near the sea, but that untouched treasures lay below.

We have now reached the margin of a new epoch in coal-mining, marked by the discovery of the safety-lamp by Sir Humphry Davy in 1815, and of the steam-engine by Watt, in 1784.* While the latter invention opened up a thousand new channels for the employment of coal, and at the same time gave the power of raising this mineral from great depths, the former enabled the miner to light his way through those dark caverns surrounded by inflammable gases with comparative safety. The uses to which coal is applicable, and the products which may be extracted from it, are almost limitless. In Britain alone it propels 5,200 locomotive engines with their trains over 9,500 miles of railway. It heats 607 iron-furnaces, besides those for smelting other ores. It sets in motion the machinery of 3,000 factories, 2,500 steam-vessels and smaller craft,

* The inventions of Watt extend over a quarter of a century; but the year 1784 was that in which he patented the invention of the parallel motion of the piston-rod, the counter for recording the strokes, the throttle valve, the governor, and the indicator. In that year also he patented a locomotive engine. The "first practical steam-boat" was the "Charlotte Dundas," built by Symington in 1801. The first effective locomotive engine was patented by Trevithick and Vivian in 1802. And at the trial on the Manchester and Liverpool railway, George Stephenson's engine, the "Rocket," gained the prize in 1829.

and lights, I dare not say how many, forges, fires, stoves, and ovens. It unlocks, when heated, invisible gases to illumine our streets, public buildings and dwellings by night, producing the cheapest, most manageable, and withal, most agreeable of lights. When gently distilled, it pours forth streams of pitch and oil, which may ultimately prove so plentiful and easy to procure as to allow the unhappy whale to move at will through the ocean, without fear of the harpoon. With the paraffine oil we can light our lamps, lubricate machinery, and, when solidified, produce candles as pure as alabaster. From the tar, the most beautiful violet and rose-coloured dyes may be elaborated, and we can unlock the gums, essences and scents, resembling those of cloves, almonds, and spices, which have lain dormant since the time when the coal plants themselves were growing.

Lastly, the very smoke of our chimneys has its use, for it is a great disinfecting agent in populous towns.

At the commencement of this century, the quantity of coal raised in Great Britain probably did not exceed 10 millions of tons. In 1819, according to Mr. R. C. Taylor, the produce of our collieries was 13 millions. In 1829, or ten years afterwards, 2,018,975 tons were shipped into the port of London alone. In 1840, the total quantity raised in Britain, according to Mr. M'Culloch, was 30 millions. Since then the increase has been rapid though fluctuating.

The quantity of coal raised in Great Britain is nearly one-third greater than the combined produce of all the remaining coal-fields of the world. This will appear from the following synopsis.

Annual Production of Coal in various countries.

		Tons.
* Great Britain and Ireland (1859)		71,979,765
† North America (1860)		21,000,000
‡ British Possessions of America		1,500,000
† France (1860)		7,900,000
† Belgium (1860)		8,900,000
† Prussia, Saxony and Hanover		12,000,000
§ Austrian Empire (1858)	Lower Austria	34,639
	Upper "	213
	Styria	1,876
	Bohemia	569,079
	Moravia and Silesia	362,522
	Hungary	110,666
	Servia and Banat	83,905
† Spain (1860)		300,000
‡ Russian Empire (estimated)		1,500,000
‡ Japan, China, Borneo, Australia		2,000,000
Total produce of all countries		128,242,673

It thus appears that the total quantity of coal raised over the whole globe is about 128 millions of tons, of which Great Britain and Ireland produce more than the half, sufficient to girdle the earth at the equator with a belt of 3 feet in thickness, and about 5 feet in width.

Now when we recollect that the coal-fields of North America are nearly 36 times larger than those of Great Britain, we may form some conception of the enormous drain to which, in comparison with that country, the mineral resources of our little island are subjected.

* "Mineral Statistics of Great Britain," by R. Hunt.
† "Situation de l'industrie houillère en 1860," Paris.
‡ Estimated. § "Mineral Statistics," 1858.

The annual increase in the production of coal since the year 1854, is about one and a half million of tons. I do not go further back, because it is doubtful whether much reliance is to be placed on estimates advanced by several authorities earlier than that year, when the "Mineral Statistics" of Great Britain, collected by Mr. R. Hunt, were published. The following are the estimates obtained through this source; and it will be observed that the increase is by no means uniform.

Coal-produce of Great Britain, 1854—59.

		Tons.
1854.	England and Wales	57,064,651
	Scotland	7,448,000
	Ireland	148,750
	Total	64,661,401
1855.	England and Wales	56,983,450
	Scotland	7,325,000
	Ireland	144,620
	Total	64,453,070
1856.	England and Wales	59,008,815
	Scotland	7,500,000
	Ireland	136,635
	Total	66,645,450
1857.	England and Wales	57,062,604
	Scotland	8,211,472
	Ireland	102,630
	Total	65,376,706
1858.	England and Wales	57,062,604
	Scotland	8,926,249
	Ireland	120,750
	Total	66,109,603

		Tons.
1859.	England and Wales	61,559,465
	Scotland	10,300,000
	Ireland	120,300
	Total	71,979,765

The increase, therefore, in the five years ending 1859, is 7,318,364 tons, being at the rate of 1,463,673, or about one and a half million of tons per annum. This increase is due to several causes, principally these:—the increase of population, the expansion of manufactures and the iron-trade, the extension of railways, and the gradual substitution of steam-vessels for sailing ships in the navies of Great Britain and Europe. Opposed, and in some measure acting as a check to these causes of increase, are to be placed the inventions for economizing the use of fuel, by the substitution of improved boilers, furnaces, and fire-places, for the wasteful kinds previously in use. The causes of increase will, however, always greatly overbalance those of decrease.

CHAPTER II.

FORMATION OF COAL.

THAT coal is of vegetable origin, is demonstrated not only by its microscopic structure, its combustible properties, but also by its position in the strata, and by the fossil plants with which it is always associated. There are at least two theories, each having its advocates, to account for the formation of coal: the first, which would assign its origin to the drifting of vegetable matter by rivers and floods into estuaries and shallow seas, where becoming water-logged it formed a bed or stratum along the bottom, and was entombed by the overspread of sediment; the second, which refers its origin to the growth of successive forests, over the areas now occupied by the seams of coal themselves.*

Without denying the probability that some exceptional beds of coal have been accumulated by drifting, and believing that drifted plants and stems of trees are of frequent occurrence in the sandstones and other strata of the Coal-measures, yet the second theory,—that of the growth of the plants *in situ*,—appears so much superior to the former in explaining the complicated phenomena which present themselves, that I feel constrained to adopt it here.

The subject will be more intelligible to the reader if he become in some degree familiar with a few of the leading members of that luxuriant flora which flourished in the Carboniferous period.

That we have only a fragmentary wreck of the plants of this period must be evident, for although vegetation attained a vigour which has never before or since been equalled, yet the number of species of coal-plants as yet determined is only about 1-20th of that of living plants now growing over Europe alone. The number of species

* The arguments and difficulties on both sides of the question are very fairly stated by Mr. Jukes, in his "Memoir on the South Staffordshire Coal-field," second edit.; and also by Mr. Salter in Part iii. of the "Iron Ores," Mem. Geol. Survey.

noticed by the great botanist Brongniart was 500, which are classified as follows:*—

Thallogens	6 species
Acrogens	346 „
Gymnosperms . . .	135 „
Doubtful	13 „

Professor Unger has raised the number to 683; but when we recollect that this includes not only the plants of Europe but of North America, it shows how much is lost to us of the vegetable productions of the Carboniferous period.

The perishable nature of plants under moisture, or water, is perhaps the principal cause of the fewness of the species preserved. For instance, there is every probability that there were grasses, mosses, and sedges, but of these we have scarcely a trace. It is probable, however, that individuals of a few species predominated very largely, as is the case now in our pine forests, and in the great cypress swamps at the mouth of the Mississippi. Dr. Lindley, by a very interesting experiment, appears to have arrived at a clue to account for the large preponderance of certain classes of plants amongst those which have been preserved. By immersing in cold water for two years a large number of plants, as nearly as possible representatives of those of the Coal-measures, he obtained the following results.—He found that the Dicotyledonous plants are in general incapable of resisting decomposition when immersed for two years, with the exception of the Coniferæ. 2ndly, That Mono-

* "Histoire des Végétaux Fossiles." (Appendix) D.

cotyledonous plants are less liable to decomposition, but that grasses and sedges perish rapidly. 3rdly, That fungi, mosses, and equisetums disappear, while ferns have a great power of endurance, the effect of immersion being only *to destroy all traces of fructification*; a satisfactory reason why fossil-ferns seldom present this portion of their structure, though the fronds themselves occur in great numbers, and in admirable preservation.*

There appears to have been an uniformity in the vegetation of the coal-period, to which there is now no parallel. The same genera, and many of the same species, ranged throughout the whole of Europe, and of North America from the Arctic regions as far south as the 30th parallel, that is to say, over a space comprehending about 45 degrees of latitude; and this uniformity of vegetation is continued vertically, for we find the same species ranging throughout the whole series of strata, sometimes amounting to a thickness of 14,000 feet.

But perhaps the most inexplicable phenomenon in connexion with this subject is the occurrence of coal and Carboniferous plants in the Arctic regions. They have been brought from Melville Island in lat. 76°. Specimens of coal, fossil-wood, and shells belonging to Carboniferous types have been brought to this country by Sir E. Belcher from Albert Land, in lat. 78° of the western hemisphere, and by Mr. Lamont from Spitzbergen, in about the same parallel in the eastern, where the country is described as frightfully barren and desolate, and entirely destitute of vegetation, with the exception of

* Lindley and Hutton: "Fossil Flora," vol. iii.

saxafrages, reindeer moss, and similar dwarfish plants.* Reasoning from analogy we could never have supposed that in latitudes now subject to the severest frosts throughout the greater part of the year, and even deprived of light for a long period, a vegetation could have flourished allied to that of the tropics, or at least to that of the warmer temperate zones of the present day. But, in truth, the period of the coal-formation was entirely unique; it was never forestalled, and has never been repeated; and of some of the most important coal plants, as *Sigillaria* and *Lepidodendron*, there are no living representatives. The general opinion of the highest authorities,† appears to be that the climate did not resemble that of the equatorial regions, but was one in which the temperature was free from extremes: the atmosphere being warm and moist, somewhat resembled that of New Zealand and the surrounding islands, which we endeavour to imitate artificially in our hothouses.

Of the plants which are commonly preserved to us, the ferns seem to take the lowest rank, and the Coniferæ the highest, the *Calamites*, *Sigillariæ*, and *Lepidodendrons* occupying intermediate positions.‡ The ferns constituted a most prolific class, occurring in vast quantities in the shales which overlie the coal-seams. The Sigillariæ, Lepidodendrons, and Calamites appear to have formed the greater mass of the coal; and the roots of the former especially (Stigmariæ) penetrate in vast quantities the

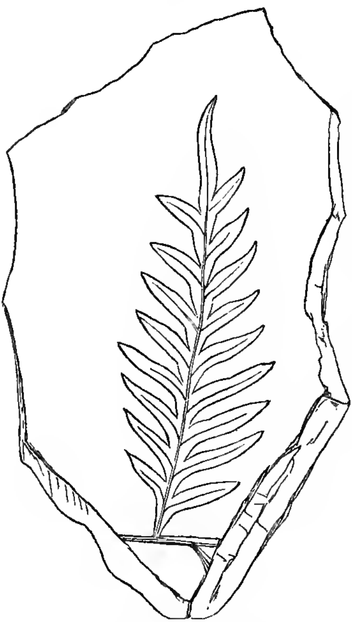
* Lignite and large trees have also been found in Iceland, but of what period is uncertain.

† See Sir C. Lyell, "Elementary Geology," 5th edit., p. 399.

‡ Dr. J. D. Hooker "On the Vegetation of the Carboniferous Period." Mem. Geol. Survey, vol. ii., p. 395.

under-clays or floors of the coal-seams. Coniferous trees, however, formed a considerable portion of the mass of the coal, and seem to have grown in company with the more characteristic plants above mentioned. I now proceed to give a short description of the genera which have been the most prolific and characteristic amongst the flora of this ancient period.

Fig. 1.



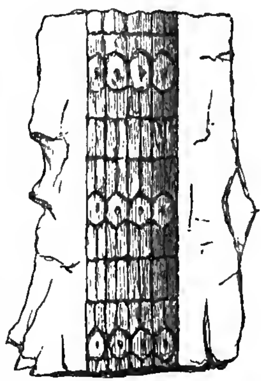
Pecopteris lonchitica.
Portion of frond: two-thirds nat. size. From a specimen in the Natural History Museum, Manchester.

FERNS.—These form a very large proportion of the Carboniferous flora; and, with the exception of their fructification, which has almost always disappeared, are preserved in great perfection. They are represented at the present day by the arborescent forms of the Tropics, which flourish in Ceylon, the islands of the Pacific, and the Indian Archipelago, where they are so abundant as to equal in numbers the whole of the phanerogamic plants.

The most abundant species in British Coal-measures are—*Pecopteris*, of which there are 60 species;

Sphenopteris, 28 species; *Neuropteris*, 24 species.* Of the 140 species known in Britain, 50 occur in the same formation in North America, some ranging from Nova Scotia as far south as latitude 35° †. It is, however, to be remarked that we know little of the habits of the ferns of the coal-period, whether they grew out of the ground, or attached to the stems of trees; and it is even extremely uncertain what proportion of the large assemblage of species were tree-ferns, as we never find the fronds attached to their stems; and the stems themselves are of extreme rarity.

Fig. 2.



Calamites verticillatus.
From a specimen in the Natural History Museum, Manchester. One-fourth natural size.

CALAMITES.‡—This is an abundant genus, and is considered by Brongniart to be represented in our day by the *Equisetaceæ*, of which the horse-tail of our swamps and ponds is a familiar example. This family extends from Lapland to the Equator, attaining the greatest number of species in the temperate zone. The fossil genera differed from the recent in the absence of the encircling sheaths at the

* I omit Cyclopteris, as it is still uncertain whether it belongs to the fern tribe. Mr. Salter believes it to be the leaf of a conifer. See "Geologist," vol. iii.

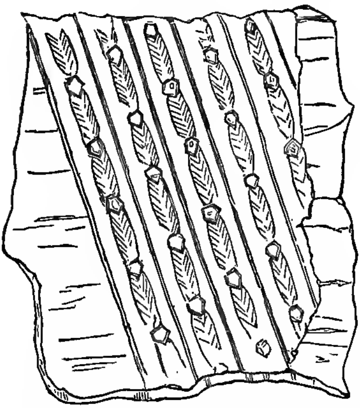
† Hooker. Ibid., p. 404.

‡ More recent researches appear to show that Calamites differ essentially from Equisetaceæ, and in many of its internal characters

joints. The Calamites almost always occur leafless, and frequently attain a length of twenty feet.

SIGILLARIA.—This plant is perhaps, *individually*, the most abundant, and has contributed more than any other to the production of coal. It has no living representatives; and about sixty species are known.

Fig. 3.



Fragment of Sigillaria. Half natural size, compressed. From a specimen in the Natural History Museum, Manchester.

Sigillaria may be readily distinguished from the stems of other plants, and of *Lepidodendron*, by the flutes and striæ of the bark being disposed longitudinally, or parallel to the axis of the trunk, and impressed with leaf-scars at regular intervals between the furrows.*

Sigillaria attained a colossal stature. Sir C. Lyell

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approaches Sigillaria. The following is the description of this genus by Lindley and Hutton: "Stems jointed, regularly and closely furrowed, hollow, divided internally at the joints by a transverse diaphragm, &c. Leaves (?) verticillate, very narrow, numerous, and simple."—"Fossil Flora."

* The following is the diagnosis of Lindley and Hutton: "*Sigillaria*, stem conical, deeply furrowed, not jointed; scars placed between the furrows, arranged in vertical columns, smooth, much narrower than the interval which separates them."—"Fossil Flora."

mentions an individual 72 feet in length, found at Newcastle.* They expand to a breadth of six to eight feet at the base, and from this taper towards the summit. Stems are frequently found standing erect on the roof of the coal, traversing several series of strata.† The character of the foliage is altogether uncertain, but the nature of the root has been clearly demonstrated by Mr. E. Binney, from observations in the Manchester coal-field. Enormous rhizomes, or root-stalks, radiating from a central axis, and spreading horizontally, had frequently been observed and described, under the name *Stigmaria ficoides*. They are covered over by multitudes of small circular indentations, from which radiate carbonized rootlets, penetrating the clay in which the rhizomes are embedded. They were at first supposed to be a distinct class of plants: but when Mr. Binney discovered, in the neighbourhood of Manchester, several upright stems of Sigillaria attached by their bases to these spreading rhizomes, it became evident that these portions stood in the relation of stem and root; and fossil-botany now labours under the disadvantage of having two generic names for different parts of the same plant.‡

* "Elements of Geology." 5th edit., p. 376.

† Several stems were found standing on the upper surface of a coal-seam at Dixonfold near Manchester.

‡ Several fine specimens are in the geological collection of the Museum of Natural History, Manchester. In one of them the upper part of the stem is a large Sigillaria, the lower part passing downwards into massive rhizomes (Stigmariæ). The internal structure both of the rhizome, and rootlet has been very clearly made out by Mr. Binney. The central axis of the former consists of a bundle of large vessels, disposed longitudinally, and surrounded by a zone of cellular tissue with

The internal portion of this plant (Sigillaria) has rarely been preserved in a state suitable for investigating its structure. A silicified fragment, however, fortunately reached the hands of one of the greatest investigators of the coal-flora, M. A. Brongniart, who was thus enabled to examine with the microscope the form and arrangement of the tissues. The result of this investigation tended to show that Sigillaria formed a peculiar family of *Coniferæ*, but without any living representative.*

LEPIDODENDRON.†—This is an abundant and large-sized plant of the coal-period; one specimen from the Jarrow coal mine being more than 40 feet in length, and 13 feet in diameter near the base. Notwithstanding its size, it has been shown by Brongmart to have its representative in the diminutive club-moss (Lycopodium) of our mountain heaths. This tribe is generally trailing; but in the tropics there are a few erect species, one of which, *L. densum* of New Zealand, attains a height of three feet.

A fragment of Lepidodendron may be easily distinguished from Sigillaria by the manner in which the leaf-scars are arranged spirally around the stem, giving it a

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medullary rays. The outer zone or bark next succeeds. The central axis of the rootlet consists of a bundle of polygonal vessels, surrounded by a ring of cellular tissue inclosed in its outer covering of bark. Journ. Geol. Soc., vol. xv.

* "Archives du Museum d'Histoire Naturelle," tom. i. 1839.

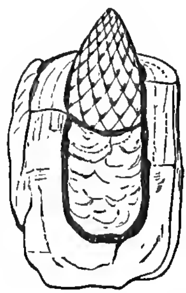
† Diagnosis:—"Lepidodendron. Stems dichotomous, covered near their extremities by simple linear, or lanceolate leaves, inserted upon rhomboidal areolæ; lower part of the stem leafless; areolæ marked near their upper part by a minute scar." Lindley and Hutton.

scale-like aspect, from which it derives its name. There are about 40 British species, distinguished by the form and arrangement of these scars.*

In the trunks of Lepidodendron small oval or conical bodies (Lepidostrobi) have frequently been found, often in numbers. They were evidently catkins or fruit-cones, divisible into two lobes—the upper covered by scales or bracts—and the seeds or spore-cases being within. See fig. 4.

When enclosed within the trunk they are found in an erect position: in other words, with their major axis parallel to that of the tree. Dr. Hooker, by a series of careful observations, has shown the lepidostrobi to be the fruit of the tree itself, and accounts for their presence in the trunks by supposing them to have been washed in by tropical rains and floods when the trunks themselves were standing hollow and decayed.† The leaves of Lepidodendron were linear, and have been found attached to the stem.‡ The root is supposed, though without any degree of certainty, to be represented by *Halonia*, a

Fig. 4.



Lepidostrobus ornatus in a nodule of ironstone. In the Bristol Museum. (Hooker.)

* Memoirs of the Geological Survey, vol. ii., part 2, p. 440, with plates.

† In Lord Stamford's museum at Enville there is a specimen of Lepidodendron, collected by Mr. H. Beckett, containing three species of shells—*Unio* (?), *modiola*, and *mytilus*.

‡ For figures of which see the "Fossil Flora."

portion of a plant covered with projecting scars spirally arranged, and originally supposed to have been a plant allied to Lepidodendron itself. At the same time the root has never been found attached, and it is not improbable that *Stigmaria ficoides* may have constituted, at least in some of its varieties, the root of both Sigillaria and Lepidodendron.

LYCOPODITES.—This was a genus of plants allied to *Lepidodendron,* with pinnated branches, and leaves inserted all round the stem in two opposite rows, not leaving clean and well-defined scars.

The genus *Knorria* of Sternberg no longer exists as such, according to the view of Prof. Göppert, who is of opinion that it is only a form of *Sagenaria* or *Lepidodendron;* and that the most common species in the Lower Carboniferous Rocks, *Knorria imbricata,* belongs to *Sagenaria Weltheimiana.**

ULODENDRON.—A plant of which the affinities are altogether uncertain. It was of considerable size, reaching 2 feet in diameter: the bark is covered with leaf-scars in quincunx order, and is impressed with large circular branch (?) scars at alternate and regular intervals.

CONIFERÆ.—It is not without significance, as bearing upon the theory of "Development," that coniferous trees formed a very important part of the flora of this ancient period of the world's history; so that, as remarked by Sir C. Lyell, their presence precludes us from characterizing the Carboniferous flora as consisting of im-

* "Ueber die fossile Flora der Silurischen der Devonischen und unteren Kohlenformation," 1859.

perfectly developed plants, the Coniferæ taking a high position in the ranks of vegetable organization.*

The prevalent type seems to have been that of the Araucarian or Norfolk Island Pine; but seed-cones resembling those of the genus *Pinus* have also been found. One specimen from the Newcastle coal-field is figured by Lindley.†

The Coniferæ of the coal-period differed from those of the present day in the large size of their pith; and the remarkable, and for a long time inexplicable, fossil, found generally in sandstones, known as *Sternbergia*, has been demonstrated by Professor Williamson to be the pith of these trees.

The little ribbed nodular mass, *Trigonocarpum*, found in great numbers throughout the Coal-measures, formerly considered as the fruit of a palm, is now believed to have been that of a coniferous plant, which like the nut of the yew-tree was enclosed in a fleshy envelope. With regard to the leaves, it is now believed that some which were formerly supposed to belong to palms, as *Nœggerathia*, a beautiful fan-shaped frond, were in reality those of Coniferæ, represented in the recent sub-tropical coniferous tree *Salisburia adiantifolia*. Thus it appears that all evidence of the existence of palms amongst the Carboniferous flora has been obliterated.

* "Elements," p. 374. The late Mr. Hugh Miller has demonstrated the existence of Coniferæ at a much earlier period—that of the Old Red Sandstone of Scotland. See "Footprints of the Creator," p. 199. Prof. Göppert has recently shown that the Coniferæ make their appearance amongst the upper Devonian rocks.—"Journ. Geol. Soc." vol. xvi.

† "Fossil Flora," vol. iii. p. 43.

These details may appear to some uninteresting; but they serve to show how necessary is a large acquaintance with the vegetation of the present, before we can rightly understand that of the past. An acquaintance, however varied, with the recent botanical productions of our own country, would tend to throw little light on the nature of that flora which flourished upon the same spot so many ages back. The tropics, and even the diametrically opposite portions of the earth, as New Zealand, Australia, and Norfolk Island, have to be searched, in order to furnish analogous productions; and where these are sought for in vain, as in the case of several Carboniferous genera, we are at a loss how to reproduce before our minds those bygone structures of which we find but the defaced ruins.

We have only here described those forms which were most prolific—many more must have existed of which we have no trace. We may, however, fully accept the opinion of Mr. Hugh Miller, that this was "a hard, dry, and flowerless vegetation." We feel pretty certain on other grounds, than the mere absence of their remains, that those orders of plants which refresh our senses with their flowers and fruits (as these terms are commonly understood) existed not in the true coal-period. There is every reason for believing that the *Rosaceæ*, *Leguminoseæ*, and a few other tribes adapted to charm the eye and minister to the wants of man, did not appear till man himself was formed; therefore, with all the luxuriance of the foliage, and the denseness and stature of the trees which overspread the great lagoons of the Carboniferous period, the general effect must have been sad and sombre in the extreme. But it persisted, through long ages, in unspeakable loneliness and silence, echoing neither voice nor sound, except when some giant of the forest snapped in twain and fell heavily into the arms of its companions. The sun shone warmly down by day upon that world, and the moon and stars by night illumined its wide plantations of dark slumberous pine-trees. But man was not there to behold, nor even a mammiferous beast of the field, or bird to fly above in the open firmament of heaven ; and only at rare intervals did the sluggish stealthy reptile force a path through the thick jungle. There was a painful absence, throughout the landscape, of the moving creature that hath life.

Having thus very briefly noticed the plants which were chiefly employed in the production of coal, we are in a position to consider the manner in which this mineral became imbedded, and thus securely stored through countless ages for the use of man.

Fossil Shells of the Coal Series of England.

The mollusca of the true Coal-measure period are confined to a few genera and species. Bivalves are most numerous, after them Cephalopods, and Gasteropods are rare.

In the Upper and Middle Coal-measures of England the most abundant, and frequently the only shells, belong to the genus *Anthracosia*, a bivalve, formerly supposed to be allied to the genus *Unio*, and hence the inhabitant of fresh water. In some of the beds of shale forming the coal-roofs, and in the bands of ironstone, this shell occurs in countless numbers, though generally flattened and distorted by pressure. Of this genus there are a great number of species and varieties. One of the most marked, *Anthracosia robusta*, from Lancashire, is represented in the plate of fossil-shells in the frontispiece. The genus *Modiola* has also its representatives in the Middle Coal-series.

Amongst the dark shales of the Lower Coal-measures, the molluscs are found often in great numbers, and in considerable variety. Their favourite haunt appears to be the roofs of the Coal-seams. Of the Cephalopods, *Nautili* and *Goniatites* are plentiful; *Orthoceras*, found plentifully near Burnley, in Lancashire. Of the Gasteropods, *Macrocheilus*, *Cirrus*, *Pileopsis*, and *Patella*; all these are scarce. Of the Conchifers, *Anthracosia* (often associated in the same bed with Aviculo-pecten and Goniatites, from which we reasonably infer that it is a sea-shell), *Posidonia* and *Aviculo-pecten*.—This last is most frequently represented by the species *papyraceus*, which occurs in the dark shale overlying some of the coal-seams of Lancashire and Yorkshire. In this position its vertical range is only a few inches; but within these limits, the flattened, paper-like valves, impressed on the dark groundwork of the shale, lie so thickly strewn that the form of the shell itself is lost, and there only appears a confused assemblage of very fine and sharply cut ribs, radiating from a number of central points, and crossing each other in mazes of net-work. The species next in numbers to the above is *Aviculo-pecten dissimilis*.

A new genus of bivalve shells confined exclusively to the Coal-formation, and occurring plentifully in South Wales, has lately been established by Mr. Salter, under the term *Anthracomya*, who believes that these molluscs were inhabitants of a muddy bottom, in which they burrowed as the Mya does upon our own shores.

Of the Pteropods, we find representatives in *Bellerophon* and *Conularia*.

Of the Brachiopods, which are so abundantly distributed in the Lower Carboniferous Rocks, forming, both as individuals and species, the majority amongst the Mollusca of the Mountain Limestone, we very rarely find any examples in the Lower Coal-series of England, with the exception of the *Lingula*. Two or three species of this shell are not uncommon in the shales of Lancashire and the Northern counties. *Spirifer, Productus, Orthis, Athyris, and Rhynconella*, have also been found in Lancashire, Denbighshire, Coalbrook Dale, and South Wales.

The Annelids are represented by *Spirorbis*, which is abundant both in the black shales of the Lower, and Limestone bands of the Upper Coal-measures.

Tracts of marine worms (*Arenicola*) frequently cover the surfaces of the fine micaceous flagstones.

It is, perhaps, as well to state that the account of the shells of the Coal-measures above given applies only to England. The Coal-formations of Scotland and Ireland belong, for the most part, to an earlier period, that of the Lower Carboniferous, and the mollusca which they contain are allied more closely to those of the Carboniferous Limestone.

Göppert's Classification of the Flora of the Silurian, Devonian, and Lower Carboniferous Formations.

Professor Göppert, as the result of an elaborate series of investigations embodied in a work just given to the world, offers the following synoptical classification of the flora of the above-mentioned formations which is specifically distinct from that of the true Coal-measures.

I. *Silurian Formation.*

1. Lower Silurian formation . .	17	species.
2. Upper Silurian formation . .	3	"
	— 20	"

These all belong to the *Algæ.*

II. *Devonian Formation.*

1. Lower Devonian . . . . . . 6 species.

Five of these are *Algæ,* one a terrestrial *Sigillaria.*—*S. Hausmanni,* Göpp.—found in Scandinavia.

2. Middle Devonian . . . . . . 1 species.

A terrestrial plant *Sagenaria Weltheimiana.*

3. Upper Devonian . . . . . . 57 species.

Ferns, Calamineæ, Equisetaceæ, Lepidodendreæ, Lycopodiaceæ, Sigillarieæ, Coniferæ, Nœggerathieæ.

1. Lower Carboniferous . . . 108 species

1. The Carboniferous Limestone contains 47 species, of which one is an *Alga.*

Note.—The student is recommended to study Dr. Hooker's interesting essay "On the Vegetation of the Carboniferous Period as compared with that of the present Day."—Memoirs of the Geological Survey, vol. ii.

2. The flora of the "Culm," belonging to the Lower Carboniferous series of Devonshire, contains twenty-three species, of which one plant is marine.

Of all the species of the Lower Carboniferous Rocks only seven pass upwards, and one single plant, *Neuropteris Loshii*, survived into the Permian period.

CHAPTER III.

FORMATION OF COAL.

WHEN Sir William Logan, twenty years ago, was engaged on his great survey of the coal-field of South Wales, he found it to be an invariable rule that every coal-seam reposed on a bed of clay (underclay) penetrated by the rootlets of *Stigmaria ficoides*.* This observation has been extended to every coal-field in Britain, and although the character of the underclay varies considerably, sometimes becoming a hard siliceous stone, yet the presence of the carbonized rootlets shows that it has borne the same relation to the coal as have the softer underclays. This observation of Sir W. Logan established the hypothesis that the plants of which coal is formed grew upon the spot where we now find them mineralized, and that the underclays formed the soil from whence they sprung.

Now these underclays are distinctly stratified, showing that they have been deposited under water; and hence

* "Geological Transactions," 2nd series, vol. vi.

it was supposed that in order to become the receptacles for the growth of luxuriant forests, they must have been elevated into dry land, and then, after having been covered by vegetation, again submerged to be over-spread by sands and clays and other sedimentary materials which combine to form the strata of the Coal-measures. This theory required a series of oscillations over a large extent of the earth's surface, which seemed rather improbable, and not in accordance with observations on changes of level which have been made in various parts of the world. That there are slow elevations, and subsidences of the surface in operation more or less extensively, is proved by phenomena exhibited on our sea-coasts,* where in some cases old sea-beaches are found at elevations far beyond the reach of the waves, and in others, where forests, and even towns, are known to be engulfed; and the whole of the geological record teaches us that similar vertical movements have been taking place from the earliest periods.

Along the eastern coasts of South America, Mr. Darwin has described the existence of a succession of terraces, rising in tiers from the sea-level up to an elevation of 1200 feet. He has shown that each of these terraces has in turn been for a long period subjected to the action of the waves, which have swept away a vast quantity of material, and hollowed out caverns in the rock.†

Now as the whole of the land, from the highest terrace down to the level of the ocean, has evidently been

* For many examples see Lyell's "Principles of Geology."
† "Voyage of the Beagle," vol. iii. p. 200.

under the sea, to have attained its present position it must have been elevated, and each coast line marks a pause in the process of elevation. Here is an example of a constant change of level, with pauses; and it probably furnishes an illustration of Nature's mode of action during the coal-period. The process, however, in this case must be *reversed*, and instead of periodical elevations it is necessary to infer a slow and gradual subsidence of the sea-bed, accompanied by pauses marked in many cases by the formation of a seam of coal.*

But another question requires elucidation. The coal-seams are associated with strata deposited under water; and all recent investigation strengthens the probability that this water was not fresh, but marine. In the northern coal-fields of England, some of the coal-seams are covered by black shales containing remains of fishes and marine shells, as *Goniatites*, *Aviculopecten*, *Orthoceras*; and along the coast of Dunbar, in Scotland, bands of limestone, with marine shells, as *Spirifer*, *Productus*, &c., rest upon coal-beds, and on the upright stems of Sigillaria.† In Coal-measures belonging to the higher portion of the Carboniferous series, bivalves which were formerly supposed to belong to the fresh-water genus *Unio*, have since been found in the same stratum with *Modiola* and *Spirifer*. For this genus

* This illustration has previously been employed by Mr. Binney, to whom, more than to any author, we are indebted for our present knowledge of the circumstances under which coal has been formed. It is, however, so apt, that I have no hesitation in reproducing it here.

† These limestones contain fossil representatives of the Carboniferous Limestone of England; and it is well known that a portion of the Coal-measures of Scotland are of earlier date than those of England.

we adopt the name *Anthracosia* of Professor King,* though believing it to have lived in seas or estuaries. Mr. Binney has shown the probability, that the little coiled shell (*Microconchus carbonarius*), is in reality a coiled *Serpula* or *Spirorbis*, which attached itself to the coal-plants;† and lastly, the minute crustacean abundant in coal-shales, and supposed to have belonged to the fresh-water genus *Cypris*, is with more probability referred to the marine genus *Cythere*. Without asserting, therefore, that there are no fresh-water strata associated with the Coal-measures, I think we may conclude that the whole formation has been essentially of marine origin—a conclusion at which we might arrive on other grounds, when we consider that the formation was at one period continuous over the greater part of Central North America, and would have required for its generation a lake of a size at least six times the area of all the great lakes of that continent united.

There are two conclusions which strike us most forcibly when reflecting on the formation of our coal-fields;—the enormous subsidence of the sea bed, and the lapse of time it must have required to produce a series of strata, with their coal-seams, in all several thousand feet in thickness.

Recollecting that every bed of true coal *represents* a land-surface, or at least a sea-level, when we find, as in the case of the coal-field of South Wales or of Nova Scotia, strata with coal-beds through a thickness of

* Annals and Magazine of Nat. Hist. Jan. 1855.

† It is scarcely necessary to remark that Serpula is a marine annelid.

10,000 or 12,000 feet, it is evident that this is a measure of the actual sinking of the sea-bed for this one geological period; or, to take an example:—the height of Mont Blanc is about 15,000 feet; now the vertical displacement which the South Wales coal-field underwent was nearly sufficient to have brought the summit of the Alps to the sea-level.

Of the lapse of time in the formation of our coal-fields we can have but a faint conception; it is only to be truly measured by Him with whom a thousand years are as one day. But the magnitude of the time is only surpassed by the boundlessness of the providential care which laid up these terrestrial treasures in store for His children, whom He was afterwards to call into being. Let me therefore dismiss this subject with one illustration. Mr. Maclaren, by a happy train of reasoning, for which I must refer the reader to his "Geology of Fife,"* arrives at the conclusion that it would require a thousand years to form a bed of coal one yard thick. Now, in the South Wales coal-field there is a combined thickness of coal amounting to one hundred and twenty feet, or forty yards, which, according to this hypothesis, would have required a period of 40,000 years for its formation. If we, now, assume that the 12,000 feet of sedimentary materials was deposited at the average rate of two feet in a century, corresponding to the rate of subsidence, it would have required $\frac{12000 \times 100}{2} + 40{,}000 = 640{,}000$ years to produce this coal-field.†

* Page 116.

† In this estimate I have adopted a medium between two extreme

I have spoken of the difficulty of conceiving frequent *elevations* of the sea-bed during the long period of subsidence in order that a land surface might be laid dry for the growth of vegetation. A much more probable supposition is, that the coal-plants were fitted to grow either partially submerged or at the sea-level. Analogy would lead us to this conclusion in the case of *Sigillaria*, *Calamites*, &c., and amongst the dense forests of larger trees, there may have been an undergrowth of reeds and grasses.

The great swamps at the estuary of the Mississippi, and those along the coasts of Louisiana, Nova Scotia, and the tropical lagoons of the African coast, furnish us with the nearest representations of the nature of those forests that have produced our coal-beds; but none of them are strictly analogous. The physical conditions of the coal-period stand alone, and we cannot but conclude that they were ordained beforehand for a great and evident purpose.

The strata which are associated with the coal consist of sandstones, which were once sand; shales and fire-clays which were once fine mud. Some of the shales are so highly carbonaceous as to be nearly black, and form impure coal called "bass." Bands of limestone occur

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estimates given by Lyell, "Elements," p. 386, 387. For a good resumé of this subject see Mr. Jukes' "Manual of Geology," p. 95 et seq.

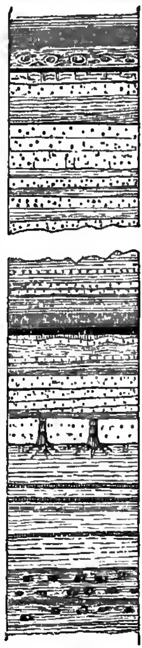
Professor Phillips attempts a calculation of the time required for the production of the South Wales Coal-field fonnded on the supposition of the sedimentary materials having been formed at the mouth of a large river, such as the Ganges, and the carbonaceous portions having been stored up at the rate of one inch in 127·2 years; the result arrived at being about half a million of years. "Life on the Earth," p. 134.

in the higher beds of the Coal-measures in England, and throughout the greater portion of the formation in Scotland.

The sandstones are frequently rippled, and obliquely laminated, showing the prevalence of currents; they also contain fragments of drifted plants. The shales have generally been deposited slowly and tranquilly. The general succession of strata which accompany coal is shown in the annexed section, taken from the neighbourhood of Wigan, and belonging to the lower Coal-measures, or Gannister series.

Fig. 5.

Succession of Strata in Lower Coal-measures, near Wigan, Lancashire.



Of coal, as a mineral, I must here say a few words. All the coal of the older formations, except the better sorts of "cannel," presents, in a cross-section, a truly laminated aspect, and consists of layers of glossy, bituminous coal, alternating with thinner bands of anthracite. The former class presents no trace of organic structure; while in the latter, under the microscope, the various tissues of Araucaria, Sigillaria, and other plants, as well as their fructification, may be detected.

There can be no doubt but that this laminated structure is the result of accumulation under water: and Bischof* adopts this view upon other considerations. He says, "The conversion of vegetable substances into coal has certainly been effected by the agency of water." The same great authority believes, that coal has been formed, not from the dwarfish mosses, sedges, and other plants which now contribute to the growth of our peat-bogs, but from the stems and trunks of the forest-trees of the Carboniferous period, such as Sigillaria, Lepidodendron, and Coniferæ.

The earthy portion of coal, which after combustion forms ash, is disseminated in minute particles throughout the entire mass, which could only have occurred by infiltration; but before woody fibre is in a state to admit of the infiltration of sediment mechanically suspended in water, it must have undergone partial destruction. Hence we may conclude that, as the forest-trees successively fell through age or accident, they were immersed in water—which must have been shallow, and which held in suspension particles of clay or sand. Mr.

* *Chemical Geology*, vol. i. Messrs. Paul and Drummond's Trans.

H. Taylor gives the following analysis of the ash of a good coal-seam from Newcastle:—

Silica	59·56
Alumina	12·19
Peroxide of iron	15·96
Lime	9·99
Magnesia	1·13
Potash	1·17
	100·00

Bischof has shown that this analysis does not much differ from that of many of the shales with which the coal is associated.

The conversion of wood into coal may take place in four different ways; namely:—

1. By the separation of carbonic acid and carburetted hydrogen.
2. " " carbonic acid and water.
3. " " carburetted hydrogen and water.
4. " " carbonic acid, carburetted hydrogen and water.

And from the mean of 67 analyses given by Bischof, it appears that by three of these processes the wood

Lost	and	Yielded.
In 1—78·0 per cent.		22·0 per cent. of coal
" 2—58·3 "		41·7 " "
" 3—45·5 "		54·5 " "

The copious discharge of carbonic acid and carburated hydrogen given off by wood in its conversion into coal, appears to have taken place for the most part during the progress of decomposition in the coal-period; for it has been found by a comparison of the analyses of true coal, with the lignite of the Tertiary strata, that the difference in the per-centage of oxygen and hydrogen in these two classes of minerals is not very great. In lignite the oxygen is only 1·54 per cent., and the hydrogen only 0·38 per cent. less than in true coal. It would therefore appear that, in the long lapse of time between the Carboniferous and Tertiary periods, the coal experienced an extremely slight loss of substance. In the coal-fields these gases are constantly escaping in jets from the shallower seams; but in the deeper parts are pent up at an enormous pressure, and materially assist the miner in his excavations, by their elastic force.

Analysis of 8 specimens of Coal from Newcastle, Glasgow, Lancashire, Edinburgh, and Durham (Bischof).

Carbon.		Hydrogen.		Oxygen & Nitrogen.		Earths.	
Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
89·2	79·1	7·2	5·3	14·5	5·5	2·9	0·5

*Analysis of Anthracite from Pembrokeshire, by Schafhäult.**

Carbon.	Hydrogen.	Oxygen & Nitrogen.		Earths.
94·10	2·39	1·34	0·87	1·30

Analysis of Brown Coal (Lignite), from Elbogen.†

Carbon.	Hydrogen.	Oxygen & Nitrogen.	Earths.
73·79	7·46	13·79	4·96

Of Britain it may be emphatically said, "whose stones are iron, and out of whose hills thou mayest dig brass." Clay-iron-stone abounds in the shales of every coal-field, either in the form of nodules or in thin courses. She has also erected more altars to Vulcan than any other country, and the products of her Carboniferous

* Dana's *Mineralogy*. † Phillips' *Mineralogy*.

rocks—the coal, ironstone, and limestone—have enabled her to take the foremost place in industrial arts.

The coal-formation is very frequently traversed by vertical fractures or *faults*, which, within a few yards or feet, completely change the series of strata and the mineral character of the district. These faults are actually vertical dislocations of the rocks, the beds having been upheaved or depressed, as the case may be, tens, hundreds, or even thousands of feet along the line of fracture. Many examples will be produced when we come to treat of the coal-fields; but I may mention that some of the faults which traverse the coal districts of Lancashire and Staffordshire dislocate the strata to the amount of 600, 700, or even 1000 yards! How graphically has that grand old geologist, the patriarch of Uz, described these throes of our great mother earth: "He putteth forth his hand upon the rock, he overturneth the mountains by the roots!"

The Coal-measures of England rest upon a series of hard and coarse sandstones and shales—called Millstone Grit; this again on a thick series of black shales, the Yoredale rocks, which pass downwards by the intermixture of thin courses of limestone into the great calcareous deposit, the Carboniferous Limestone. This last formation attains in Derbyshire a thickness of 5000 feet, and is surcharged with marine fossils throughout; indeed it is almost wholly composed of the shells of mollusca, the calcareous habitations of corals, or the broken skeletons of Crinoidea or "stone lilies." These last must have covered the bottom of the ocean in countless myriads, forming miniature forests, which rose generation after generation upon the accumulating layers of their perished ancestors, until their remains were sufficient to form thick beds of limestone, extending for many miles in every direction. In some parts of Derbyshire and Yorkshire the limestone appears to be composed of little else than the disjointed skeletons of Crinoidea.

The Coal-measures are overlaid by the Permian formation, consisting of three members: the lower composed of red and purple sandstones, marls, calcareous conglomerate, and breccia; the middle, of magnesian limestone of the north-eastern counties; the upper of gypsum, marls, and sandstones. This formation is unconformable to the Coal-measures, and to the Trias which succeeds it.

Next in succession is the Trias or New Red Sandstone, which, in the absence of the Permian strata, sometimes rests directly upon the Carboniferous rocks. It consists of two members, the Bunter and Keuper; the middle member, the Muschelkalk, being absent in Britain.

The Bunter Sandstone consists of three members: the lower, soft red and variegated sands; the middle, quartzose conglomerates and red pebbly sandstone; the upper, soft streaked and variegated sands. Upon this the Keuper series rests unconformably, the upper surface of the Bunter Sandstone being frequently eroded and waterworn. The Lower Keuper Sandstone is introduced by calcareous breccia, and passes upwards into the Red Marl.

We are now in a position to comprehend in some measure the formation of a coal-seam in olden time.

Let us suppose that a certain bed of coal has been completed by the growth of luxuriant plants over a low-lying tract subject to inundations from the sea. Rising ground of granitic or schistose rocks in the distance defines the margin of the basin and the boundaries of a continent from which the sedimentary materials of the coal-strata are derived. That growth of vegetation marks a period of rest; but now a slow subsidence of the whole tract commences. The brackish waters of the estuary, and the salt waters from the ocean invade the jungle, carrying dark mud in suspension, with floating stems of trees and fronds of ferns. Presently the mud subsides, and covers in one uniform sheet the accumulated vegetation of centuries. The process of subsidence goes on, while the sea-currents and rivers pour into the estuary fine sand and mud, in which branches and stems of trees from the uplands are included. This process continues until the sinking of the ocean-bed either altogether ceases or is counterbalanced by the rapidity with which the sediment is deposited. The basin becomes gradually shallower, and the plants begin to reappear, commencing perhaps at the coast, and creeping seaward until the whole basin is again overspread by a forest of huge cryptogamic trees, arborescent ferns, and conifers, with a dense undergrowth of giant grasses. These, generation after generation, flourish and die, their leaves, branches, and trunks falling around and gradually accumulating till the pulpy mass attains a thickness of 20, 50, or 100 feet. The process concluded, the basin again commences to subside, the waters return and bury the mass for hundreds of centuries; stratum after stratum accumulates, till the vegetable pulp is subjected to the pressure of, it may be, thousands of feet of solid matter. Meanwhile chemical as well as mechanical changes ensue, and in process of time what was once a forest is changed into a bed of coal. By a repetition of this process, with local variations, we may conceive the formation of any number of coal-seams, amounting, in some districts, to 50 or 60, and embraced within a vertical thickness of several thousand feet of shales, clays, and sandstones. Ages roll on, the strata are moved from their foundations; upheaved from the sea-bottom, the breakers and currents sweep away a portion of the covering, and the mineral treasures are brought within the reach of mining industry.

The following view of the formations which lie immediately above and below the Coal-measures may prove useful for reference. It is applicable, I believe, to the whole of Britain. The tripartite division for the Coal-measures of England and Wales is not, as yet, generally recognised, but every day's experience tends to make such a division more than probable.

Tabular View of the Trias, Permian, and Carboniferous Series in England and Wales.

New Red Sandstone or Trias	Keuper . .	Red marl Lower Keuper sandstone.
	Bunter . .	Upper mottled sandstone Conglomerate beds Lower mottled sandstone.

Permian Rocks		Upper and lower magnesian limestones and marls of the Northern counties.
		Lower red sandstone of Lancashire, Yorkshire, &c.
		Red sandstones, marls, conglomerates, and breccia of the Central counties and Salop. (Rothe-todte liegende.
Carboniferous Rocks	Upper Carboniferous	Upper Coal-measures with Spirorbis limestone and thin coal-seams.
		Middle Coal-measures with thick coal-seams.
	Lower Carboniferous	Lower Coal-measures or Gannister series, with thin coal-seams and Lower Carboniferous fossils.
		Millstone grit with thin coal-seams.
		Upper limestone shale, or Yoredale rocks.
		Carboniferous limestone; with shales, sandstones and coal in the Northern counties, and Scotland.
		Lower limestone shale
Old Red Sandstone and Devonian rocks.		

Having given a brief sketch of the nature of coal, its origin, and the strata with which it is associated, we are now prepared to pass on to the consideration of the coal-fields.

PART II.

CHAPTER I.

THE GREAT COAL-FIELD OF SOUTH WALES.

THE coal-field of South Wales is the largest in Britain, with the exception of that of the Clyde Basin, and contains almost as great a vertical thickness of strata as any coal-field in the world, amounting to upwards of 10,000 feet.

It is separated by Caermarthen Bay into two unequal portions. That to the east of the bay stretches to Pontypool, in Monmouthshire, a distance of 56 miles, and is the larger portion. The smaller extends to St. Bride's Bay, a distance of 17 miles, and is washed by the waves of the Atlantic. The greatest transverse diameter is 16 miles, in the meridian of Neath, in Glamorganshire.

The general form of the coal-field is that of an oval basin or trough, lying nearly east and west. It is deeply indented by the bays of Swansea and Caermarthen, which overspread the upturned edges of the strata as they cross from shore to shore. It will therefore be understood, that from the oval form of the coal-field, the highest strata occur near the central axis; and that in proceeding from this line either to the north or south, we cross transversely the up-tilted edges of the beds, reaching in succession lower coal-seams with their accompanying sandstones and shales, then the Millstone Grit, Carboniferous Limestone, and finally, the Old Red Sandstone. Owing, however, to the occurrence of an arch, or anticlinal bend of the strata near the centre of the trough, the above description is only approximately correct, as in reality the highest strata occur a little to the north and south of the central axis.*

Scenery.—Along its northern borders, the coal-field partakes of a mountainous character, rising into lofty tabulated hills indented by deep valleys, along whose sides the beds of coal crop out, and are worked by means of galleries far into the hills.

Beyond the limits of the Coal-measures, the siliceous sandstones

* These phenomena are illustrated by the transverse section (Fig. 6), where the Coal-measures are shown to be bent upwards in the centre of the trough.

Fig. 6.—SECTION ACROSS THE COAL-FIELD OF SOUTH WALES.

Length about 20 miles.

NORTH.

SOUTH.

A. Coal-measures, with coal. B. Millstone Grit. C. Carboniferous Limestone. D. Old Red Sandstone.

and conglomerates of the Millstone Grit form an encircling zone; and from beneath these, the still harder rocks of the Carboniferous Limestone rise to the surface, and present towards the north a range of scarped terraces, often broken through by valleys and gorges which have been determined by faults, but on the whole preserving a general direction parallel to the *strike** of the beds, and attaining elevations of 2,000 feet. Along the southern boundaries of the coal-field, these Lower Carboniferous formations produce rich and varied scenery, but not of so bold and elevated a character as along the northern margin.

Surveys.—Following the track of the Ordnance Surveyors, the geological delineation of this great coal-field, at first commenced by Sir E. Logan, was subsequently completed by Sir H. T. De la Beche and Mr. Williams, during 1837 and following years. They have left us a series of beautifully executed maps and sections, presenting the details as far as they were discoverable at a time when the coal-field had been very partially explored by mining operations. Of these documents, it was stated by one competent to judge, that they at once placed the landed proprietors in the possession of information which it would have taken 30 years to acquire by the advance of mining enterprise.

* The "strike" is a term to express the horizontal direction of the strata, and is perpendicular to the "dip."

General Succession of Strata, and their thicknesses, in Monmouthshire.

Coal-measures.—Shales, with ironstones; sandstones, including the "Gower series," and *coal-beds* of which there are about 25 more than 2 feet thick. Total thickness, 11,650 feet.

Millstone Grit (Farewell Rock).—Beds of hard sandstone and conglomerate, with partings of shale (Merthyr Tydvil), thickness 330 feet.

Carboniferous Limestone.—Upper beds consisting of alternating dark shales with bands of limestone, passing downwards into massive beds of the latter, thickness 1000 feet.

Old Red Sandstone.—Conglomerate, red and brown sandstone, marls, and calcareous cornstones, 8000 to 10,000 feet in thickness.

Westward of Swansea Bay the Millstone Grit disappears, and the Lower Coal-measures rest directly upon the Carboniferous Limestone. At Haverfordwest this latter also vanishes, and inland from St. Bride's Bay the Coal-measures repose on Lower Silurian Rocks.

Anthracite and Bituminous Coals.—It is well known that a remarkable change overtakes the coal-beds when traced from the east towards the west. While in the former direction they are bituminous, or gaseous, upon reaching the centre of the area, the same coal-seams become semi-bituminous, or "steam coals," and further west, gradually pass into anthracite. Sir H. De la Beche states that this change takes place along a plane, dipping gently towards the S.S.E.; so that in the same spot, while the coals at the base of a hill may be anthracitic, those which outcrop along the heights above may be bituminous. Nor is this alteration in the character of the coals acompanied by outbursts of igneous rock, or by violent crumplings and contortions of the beds, as is the case in the Alleghany mountains of America, where a similar change has been produced; on the contrary the strata are but slightly thrown out of the horizontal position. Other causes must therefore be sought for. The doctrine of central heat appears to me a sufficient explanation, and indeed the only one which can be applied to this case. When we recollect that the temperature increases in proportion to the depth, and that in South Wales the lower coal-beds have been originally overlaid by several thousand feet of strata, since swept away, the heat to which they have thus been subjected was probably sufficent to have driven off, wherever escape was possible, the gaseous elements. There are, however, many difficulties which appear inexplicable, especially the fact of the coal of the western districts having become more anthracitic than that of the eastern, but observations over a large area of the earth's surface teach us to expect that the increase of temperature in descending from the surface is subject to much variation and irregularity, arising from changes in the composition, arrangement, and density of the rocks themselves; and other causes of which we are ignorant. To some such cause it may be owing, that the strata of the western side of the coal-field may have been exposed to a higher degree of internal heat than the eastern, and thus become altered into anthracite.

General Succession of the Coal-series in Glamorganshire and Monmouthshire.

Upper Pellengare Series, more than 3,400 *feet.*	1. Sandstones and shales down to the Mynydd Isslwyn coal, 5/6. 2. Strata, with 26 coal-seams down to the Hughes vein; 9 seams over two feet in thickness.
Pennant Grit Series, 3,246 *feet.* (Swansea.)	Hard and thick-bedded sandstones, &c., with 15 coal-seams; 5 over two feet in thickness.
Lower Coal-Measures 450 to 850 *feet.*	Principally shales, rich in iron-stone and coal-seams, of which there are 34 in all, and 8 above two feet in thickness.
Millstone Grit.	Represented in the South by the Gower Series.

It will be observed from the above general summary, taken from the Memoir of Sir H. T. De la Beche,* that the richest coal-bearing strata lie at the top and bottom of the formation, the central portion or Pennant Grit being comparatively impoverished.

The Lower Coal-measures along the southern borders of the field form a well-marked zone, very rich in coal and ironstone, and distinguished by a remarkable group of fossil shells of marine genera; some of the species—as is also the case in the lower measures of the northern counties—descending into the Carboniferous Limestone. It is a very remarkable fact that these lower measures appear to form the upper limit of this essentially marine fauna, the shells which occur in the higher beds being confined to the genus *Anthracosia;* and whatever may have been the conditions under which this genus of molluscs lived—whether (as once supposed) in fresh water, or brackish, or marine—the extent of its range, as compared with the Goniatites, Nautili, Pec-

* Memoirs of Geological Survey, vol. i.

tens, Spirifers, and other shells of the Lower Coal-measures, seems to point to some marked physical difference in the original state of the Middle and Lower portions of the Coal-formation.

The fossils of the Lower Coal-measures are found principally in the ironstones, and have been determined by Dr. Bevan. I shall enumerate them presently. The coal-seams occur in greatest number and thickness along the southern outcrop, where the series attains a thickness of nearly 1000 feet.

Pennant Grit Series.—The lower measures are surmounted by a great series of sandstones, introduced by the "Cockshoot rock," and included under the general term Pennant Grit, the same by which this series is designated in Somersetshire. These sandstones form a fine range of escarpments, often reaching 1000 feet in elevation, and within these escarpments is enclosed the great central table-land of Glamorganshire composed of the higher strata of the Coal-measures. Along the deep valleys by which this region is intersected the coal-beds often crop out, and are worked by tunneling into the heart of the hills. The whole series of strata, from the uppermost Pellengare beds down to the Millstone Grit, is from 10,000 to 12,000 feet in thickness *without reaching the top,* containing about 80 seams of coal, of which 25 are from two feet upwards, with an aggregate thickness of 84 feet of workable coal.* This great series is only surpassed in depth by that of Nova Scotia and Saarbrück.

* The combined thickness of all the coal-seams, small and great, is stated by Professor Phillips to reach 120 feet.

The following summary of the known coal-seams in several important districts, has been kindly supplied by Mr. Salter, of the Geological Survey: I have not thought it necessary to insert all the names of the coals:—

Name of District.	Total No. of Coals.	No. of Coals above 2 feet in thickness.	Principal Coals.
1. Merthyr Tydvil	54	16	Mynydd Isslwyn, 5/6; Upper Troed, 4/0; Yard, 3/2; Upper 4 feet, Troes y fran, 8/6; Lower coal, 4/0.
2. Ebbw Vale	52	8	Elled vein, 3/4; Big vein, 4/9; 3-quarter vein, 3/4; Engine vein, 5/9; Gloien Goch, 4/0; Old coal, 5/6.
3. Cwm Telcry ...	29	13	Soap vein, 2/8; Elled and Big veins, Bydyllog, 5/0; Old Coal, 5/0.
4 Pont-y-Pool	25	12	Mynydd Isslwyn, 5/6; Red vein, 8/6; Rock vein, 8/0; Meadow vein, 9/6; Bottom, 5/0.
5. Pellengare and Pont-y-gwasted	51	26	Goch vein, 13/6; Big vein 6/0; Tryglo, 5/0; Gwendrath, 3/0; Coed Bach, 2/6; Pimp quart, 3/9.
6. Llandibic, Caermarthenshire	—	19	9-Foot, Pimp quart, 3/9; Gwyryd, 3/0; Stanllyd, 6/9.
7. Llangeinor, Glamorganshire	31	14	Llangeinor, 4/0; Coedafydd, 5/0; Upper 6-foot, Furnace vein, 12/0.
8. Cambrian Iron-Works	..	6	
9. Bryn Coch Dyffryn	13	8	
10. Llw chwr and Ren-Clawdd, Glamorganshire	68	16	Faith seam, 4/0; Great vein, 9/0; Glo Broight, 4/6; Rock vein, 5/0; Fiery vein, 4/0; Frog-lane, 3/0; Big vein, 6/0.
11. Pellengare to Bishopstown, near Swansea	62	25	Church vein, 4/0.
12. Cwm Trwch, near Ystradgynlas, Brecknock	9	6	Nine-feet vein, Brass vein, 4/0; Try Glo, 2/0; Lumpy vein, 2/0.

Ironstones.—The Lower measures are the chief repositories of ironstone, as at Merthyr Tydvil, and at Taffe Vale near Cardiff. They are seldom more than five inches in thickness, and frequently contain marine shells, fish, and plants. The following is an analysis of the principal bands, made at the Museum of Practical Geology.

Analysis of Ironstones.

	Carb. Iron.	Earthy Matter.	Metal.
Upper vein, Ystradgynlas ..	86·0	14·0	41·5
Another vein, do. ..	72·4	27·6	34·9
Cwm Phil vein	75·4	24·6	36·4
Pendaren red vein ..	75·4	24·6	36·4
" Jack vein ..	55·5	44·5	26·6
Black-band, Pontypool ..	79·5	20·5	38·4

The yield of these Coal-measure ores, even in conjunction with the hæmatite from the Carboniferous limestone, is not sufficient to supply the enormous consumption, and large quantities are imported from Northamptonshire and other districts. In 1859 there were, in the anthracite district, 18 furnaces in blast, and in the bituminous district, 147 furnaces, producing in all 985,290 tons of iron.

Faults.—The fractures which traverse the South Wales coal-field are, in the great majority of cases, referable to one system, perpendicular to the longitudinal axis of the basin, and therefore ranging north and south. A very few range from east to west. The remarkable parallelism of these fractures, and their direction with reference to the general arrangement of the strata, leave no doubt that they have all resulted from one system of disturbing forces.

Resources.

In attempting to estimate the duration of the supply of coal from this vast repository I am aware of the difficulty of the task. When we regard the enormous amount of fuel which is stored up throughout a thickness of strata out of which might be cut a mountain about three times the height of Snowdon, having a basis of a thousand square miles, and which, as Mr. Vivian has shown, could supply the whole consumption of Britain for nearly 5000 years, it seems almost profane to assert that at least one half of this store must lie for ever beyond our reach, and thus, as far as man is concerned, to have been made for nought. If, therefore, there are those who consider 4000 feet as too narrow a limit, it will be satisfactory to them to be assured that they have here a store of fuel well-nigh limitless, and which if it had been drawn upon to its present extent since the days of the Noachian deluge, would even still be unexhausted.

I shall however here adopt, for the reasons stated in a former chapter, the limit of 4000 feet,* which will require a deduction of one-half the full quantity. From this we must deduct one-third for the quantity already raised and for waste, and also disregard all seams of coal under two feet in thickness.

This coal-field, if opened up to an extent commensurate with that of Yorkshire, ought to yield 13,000,000 of tons annually. That it will eventually attain this

* I must refer the reader to the closing pages of this Essay for an exposition of my reasons for adopting a depth of 4000 feet as the vertical limit of coal-mining. Part iv., page 219.

figure, the rapid increase in the production within the last ten years fully justifies us in anticipating.

Estimate of the Mineral Resources of the South Wales Coal-Basin.

1. Superficial area	906 square miles.
2. Greatest thickness of Coal-measures with coal	10,000 to 12,000 feet.
3. Number of coal-seams from 2 feet and upwards, 25, giving a thickness of	84 feet of workable coal.
4. Total quantity of coal (corrected for denudation)	48,000 millions of tons.
5. Deduct one-half for quantity below 4000 feet, leaving	24,000 millions of tons.
6. Deduct one-third for waste and quantity already extracted, leaving for future supply	16,000 millions of tons.

7. The quantity raised in 1859 was upwards of 9½ millions of tons. Supposing that the production of future years amounts to ten millions, the above supply would last for 1,600 years.*

Fossils.

The ironstones and shales of the Upper and Middle portion of the Coal-measures contain shells of the genus *Anthracosia* only; but when we descend into the lower strata which overlie the Millstone Grit, we find a series of mollusca, closely resembling and sometimes identical with those of the Lower Coal-measures of the north of England. They are contained generally in the ironstone bands, and have been determined by Mr. Salter from the collection of Dr. Bevan.†

* Mr. Vivian's estimate is 5000 years, which would be nearly that of my own, if we add the quantity of coal below 5000 feet, and take the production at eight millions of tons, which was the amount in 1858.

† For description and figures of many of these fossils, see *Iron-Ores of Great Britain*: Part iii.

1. Top—Black-band-ironstone.—Fish : *Rhizodus, megalychthys.* Shells : *Modiola.*
2. *Soap Vein.*—Tracks of *Annelids,* and a new genus of bivalve shells peculiar to the Coal-measures.—*Anthracomya.**
3. Ironstone above "3-quarters Coal.—"*Anthracomya.*
4. Ironstone over Bydyllog Coal.—*Athyris planosulcata :* a shell also found in the Carboniferous Limestone.
5. Darin Pins Ironstone.—*Anthracosia, Anthracomya, Myalina* (same species as in the "Pennystone" band of Coal-brook Dale). *Avicula* (?).
6. Ironstone over "Engine Coal."—*Spirifer,* and *Productus.*
7. "Old Coal" black band.—*Anthracosia acuta,* and *A. ovalis,* both common species in the Coal-measures.
8. Spotted Vein.—Tracks of *Limulus,* a crustacean allied to the King Crab—and *Spirorbis carbonarius.*
9. Bottom Vein.—Fish : *Megalichthys, Rhyzodus, Palæoniscus, Amblipterus, Pleurocanthus, Helodus, Pecilodus, Pleurodus.*
10. Bottom Rosser Vein.—Fossils of the Carboniferous Limestone. *Spirifer bisulcatus, Orthis resupinata, O. Michelini, Conetes Hardrensis. Streptorhynchus crenestria. Productus semi-reticulatus, Edmondia Unioniformis. Axinus Carbonarius. Productus Cora, Conularia quadriculeata, Nautilus falcatus.*

CHAPTER II.

BRISTOL AND SOMERSETSHIRE COAL-FIELD.

At an unusually short distance from the base of that range of Oolitic escarpments which stretches in an ever-varying line from Gloucestershire to Dorsetshire, lies the Bristol coal-field. The thick series of formations which in the midland counties intervene between the Coal-measures and the Lias, are here either greatly reduced in depth or altogether absent; and hence we

* Established by Mr. Salter—*Iron-Ores of Great Britain.*

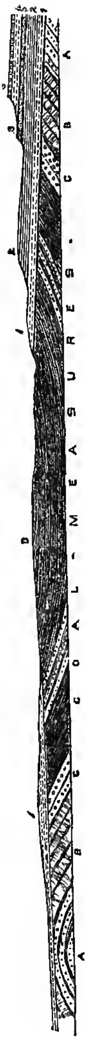


Fig. 7.—SECTION ACROSS THE BRISTOL COAL-FIELD.

WEST. Cotteswold Hills. EAST.

A. Old Red Sandstone.
B. Carboniferous Limestone.
C. Millstone Grit.
D. Coal-Measures, with coal.
5. Lower Oolite.
4, 3, 2. Upper, Middle, and Lower Lias.
1. New Red Marl (Trias).

may pass from the one formation to the other within a distance of a hundred yards.*

The northern part of the coal-field forms a trough lying north and south, narrowing towards its northern limits, and expanding in the opposite direction, till, east of Bristol, it reaches a width of seven miles. The beds rise at high angles along and beyond the edge of the basin. The Millstone Grit and Carboniferous Limestone form parallel belts. Upon the upturned edges of these more ancient formations the New Red Marl and Lias rest almost horizontally (see Section No. 7). South of Bristol, the boundary of the coal-field, marked by the range of limestone hills, sweeps round to the westward, and is lost under the sea beyond Nailsea Moor, near Clevedon in Somersetshire. South of this the Coal-measures underlie the Liassic formations of Dundry Hill, and encircle the large mass of Carboniferous Limestone near Congresbury.

* This district is illustrated by the Geological Survey Maps, 19, 35, and Sections, sheets 14, 15.

Over the greater part of this area the coal-formation is buried at moderate depths under newer horizontal strata.

Along the southern boundary of the coal-field the Carboniferous Limestone of the Mendip Hills rises to the surface, trending from west to east, till lost beneath the Lias and Oolite, W. of Frome. I am assured, however, by Mr. Etheridge, that the basin-shaped structure of the Carboniferous Rocks under the Lias and Oolite has been thoroughly established by actual sinkings and borings through these newer formations, so that the lowermost coal-shales or Holcombe Series do not pass eastward of a line joining Bath and Frome. On reaching Mells, the lowest beds bend round to the North, and take a course through Buckland, Norton St. Philip, Midford, Twiverton (where coal is worked), and North Stoke. It will be observed that this outcrop is in the line of the great N.—S. dislocation, which passes by Chipping Sodbury and Cleeve Bridge near Doniton.*

The extreme length of this coal-field, from its northern apex at Cromhall to the flanks of the Mendip Hills, is about 25 miles, the general strike of the beds north of the valley of the Avon being north and south, and over the area south of this line from west to east. About one half of the northern portion is over-

* I was formerly of opinion, with many others, that the coal-field stretched eastwards from the Mendip Hills under the Oolites, by Bath, Bradford, and Frome, until informed to the contrary by Mr. Etheridge, who is well acquainted with the trials which have been made to prove coal in this direction. It is very probable, however, that the Coal-measures roll in again under the Cretaceous rocks of the Vale of Wardour.

laid by horizontal strata of the Triassic and Oolitic periods, and of the southern part 9-10ths are covered over in this manner; yet the existence of the underlying coal-field is abundantly proved, not only from theoretical considerations but by actual sinkings for coal. Shafts penetrating the Lias and Red Marl into the coal have been sunk at Paulton and Timsbury; and another near Radstock, commencing in the upper beds of the Lias, reaches coal at 200 fathoms.*

The succession of strata in the neighbourhood of Bristol has been determined by Mr. D. Williams,† and is as follows:—

Succession of Strata near Bristol.

Lias	Lower, Middle, and Upper Lias.	
Trias	Red Marl. Dolomitic conglomerate.	
Coal-Measures	Upper Series, with 10 coal-seams ..	1,800 feet.
	Central, or Pennant grit, 5 coal-seams ..	1,725 „
	Lower shales, 36 coal-seams	1,600 „
Millstone Grit ..	Hard silicious grits, &c.	950 „
Carboniferous Limestone	.. ..	2,338 „

There is thus a total thickness of strata with coal of 5,125 feet, separated into two divisions by a series of hard, massive sandstones (Pennant grit), which will prove a serious obstacle to sinking in search of the lower coals. Of the 51 coal-seams above mentioned only 20 are 2 feet and upwards in thickness, producing 71 feet of coal.

* "Lectures on Geology," by Mr. R. Etheridge, 1859. A little book containing much valuable information about the Bristol coal-field; and to its author I am indebted for many details concerning this district

† Mem. Geol. Survey, vol. i., p. 207.

The Coal-measures have been arranged by Mr. Etheridge under the following subdivisions.*

Upper ..	..	Radstock Series.
		Farrington "
Middle ..	..	The Pennant "
Lower ..	..	Bedminster "
		Ashton, or Holcombe "

The Radstock series (see section below) occupies a small area in the southern part of the coal-field between Kilmersdon and Farmborough.

The Farrington series forms a much larger area—from Holcombe on the South to near Brislington on the North, and from Combe Hay on the East to Chew Magna on the West.

The Bedminster series encircles the last in a band about 1½ mile broad along the East, and on the West occupies the greater part of the flat ground around the Limestone inlier of Congresbury and Backwell, stretching to the sea-coast under Nailsea Moor, Kenn Moor, Nempnet and Puxton. It also forms the greater part of the Northern district.

The lowest series of Holcombe forms a narrow belt lying immediately over Millstone Grit or "Farewell Rock." Along the edge of the Mendips, and at Twiverton, the strata are highly disturbed and dislocated.

The following is the general succession of the Coal-series, for which I am indebted to Mr. Etheridge; and which is very similar to that published by the Geological Survey.

* "Lectures on Geology."

General Coal-series of the Somersetshire Coal-field.

North Side.

Series	Name of Coal-seam, &c.	Ft.	In.
	Red Sandstone and Marl at Coal Pit Heath	270	0
	Radstock Series (Not represented in the Northern district.)		
Farrington Series.	*Coal*	1	4
	Shale and rock with thin seams	102	0
	Hard Seam	3	0
	Shale with coal, 1ft.	123	0
	Hollybush Coal	3	0
	Shales and Sandstone	52	0
	Great Seam (in 3 beds)	5	0
	Strata, &c.	238	0
	Coal	1	6
	Strata	215	0
Pennant Series.	Hard sandstone with a few beds of shale—and 3 coal-seams, each about two feet in thickness	1500	0

South Side.

Series	Name of Coal-seam, &c.	Ft.	In.
	New Red Sandstone and Marl	120	0
	Dolomitic conglomerate ("millstone")	6	0
	Sandstone and shales	240	0
	Withey Mill Seam	1	0
	Strata		
	Great seam of Clair Down	2	0
	Strata, with two thin seams	67	6
	Middle seam	1	8
	Strata	100	0
	Silven vein	2	6
	Strata	40	0
	Little seam	1	6
	Strata (*with Bull seam, &c.*)		
Farrington Series.	*Sulphurous coal*	2	0
	Strata	36	0
	Cat-head seam	2	0
	Strata	36	0
	Three-seam coal	3	0
	Shales, &c., with *Anthracosia*	54	0
	Peacock coal	2	0
	Shales	36	0
	Shaley seam	2	0
	Shales	36	0
Pennant Series.	Principally hard sandstones, with 5 seams of coal	1500	0

General Coal-series of the Somersetshire Coal-field—cont.

North Side.				South Side.			
	Name of Coal-seam, &c.	Ft.	In.		Name of Coal-seam, &c.	Ft.	In
Bedminster Series.	*Cock-seam* . . .	2	0	Bedminster Series.	*Small Coal* . . .	3	0
	Sandstone . . .	42	0		*Dead Course*, or shell-seam . .	3	0
	Hen-seam . . .	1	6		*Garden Course*. .	3	6
	Strata	180	0		*Strap-seam* . . .	2	6
	Coal	2	6		*Great Course* . .	4	0
	Strata	540	0		*Firestone-seam* . .	3	0
	Britton's seam . .	1	2				
	Strata	300	0				
	Coal	3	0				
	Strata	78	0				
	Shelly Vein Coal .	3	0				
	Strata	54	0				
Holecombe Series.	*Hard-seam* . .	1	7	Holecombe Series.	*Dungy Drift* . .	2	0
	Sandstone and shale	360	0		*Hard Coal Drift* .	3	0
	Coal	4	0		*Perkin's Course* .	2	0
	Strata	60	0		*Foot-coal* . . .	2	0
	Great-seam . .	4	0		*Branch-coal* . .	4	0
	Sandstone . . .	60	0		*Golden Candlestick*	2	6
	Coal	1	6		*North Sheets* . .	4	0
	Shale	120	0		*Cat* (red ash) . .	1	0
	Coal	2	0		*South Sheets* . .	3	0
	Shale	48	0		*Riband-coal* . .	1	2
	Slate-seam . . .	1	8		*Standing-coal* . .	4	0
	Shale	24	0		*Fern Rag* . . .	2	6
	Coal	1	0		*Stone Rag* . . .	3	0
	Strata	24	0		*Callows-seam* . .	4	0
	Coal	1	0		*Penrick*, or *Blackstone-coal* . .	3	0
	Sandstone . . .	60	0		*White-axen* (ash) .	2	6
	Stoney-seam . .	1	4		*Firestone-seam* . .	2	0
	Strata	180	0		Millstone Grit.		
	Coal	4	0				
	Millstone Grit. .	180	0				

Note.—The *terms* used at the sides of the columns are intended to show that the seams, in the North and South areas of the Coal-field, are most likely the same under different names, and are here attempted to be correlated.

In estimating the resources of this coal-field, large deductions must be made on several accounts. First, for the disturbed, folded, and contorted state of the strata along the borders of the Mendip Hills and other places, while towards the centre of the Somersetshire basin, many of the coal-seams are buried at depths between 4000 and 5000 feet, with the Pennant grit interposed; and secondly, the coal-seams are generally so thin as to render many of them unavailable at great depths. I have therefore deducted one third in the following estimates.

Estimate of Resources.

1. Area (of which only 45 square miles are not concealed by newer formations)	150 square miles.
2. Greatest thickness of measures with coal ..	5,125 feet.
3. Number of coal-seams from 2 feet and upwards, 20, giving a thickness of coal of ..	71 "
4. Total original quantity of coal (corrected for denudation)	4,148 millions of tons.
5. Deduct for quantity inaccessible, spoiled, &c., one-third, leaving	2,766 " "
6. Deduct for quantity already worked out, one-tenth, leaving	2,489* " "
7. Deduct for quantity below the depth of 4,000 feet, one-fifth; leaving for future supply about	2,000 " "

8. Dividing this quantity by 750,000 tons, the produce for 1859, we find that this coal-field would require 2660 years to become exhausted.

The chief conclusion to be drawn from the above results is, that this coal-field is capable of yielding at least five times the present quantity of coal if worked to the extent of its capabilities.†

* *i. e.*, under the newer formations, 1742 millions. The actual coal-field contains only 747 millions.

† The production above stated (750,000 tons) is calculated by subtracting 500,000 due to the Forest of Dean, from 1,250,000, the total quantity raised in both coal-fields in 1858. Hunt's "Mineral Statistics," 1859.

CHAPTER III.

FOREST OF DEAN COAL-FIELD, GLOUCESTERSHIRE.*

THE structure and resources of this coal-field are now thoroughly understood. It forms a more perfect "basin" than any other coal-field in England, as the strata everywhere dip from the margin towards the centre, except at one part of the western side, where the oval outline is interrupted for a short distance.†

The Coal-measures are surrounded by belts of Millstone Grit and Carboniferous Limestone, which generally rise considerably above the tract of the Coal-measures they enclose, just as the banks of a lake are higher than the lake itself; and the Carboniferous Limestone in turn rests upon a bed of Old Red Sandstone. The general structure resembles that of the South Wales coal-field in miniature, and the transverse section (Fig. 6) illustrates the coal-basin of the Forest of Dean as well as that to which it more especially refers.

Scenery.—The scenery around the skirts of this coal-basin is rich and varied. The eastern ridge of the Carboniferous Limestone overlooks the vale of the Severn, and commands the escarpment of the Cotteswold Hills of Gloucester and Somerset. At the opposite side of

* The Royal Forest covers a space of 23,000 acres, of which 11,000 are in timber. Deer formerly abounded, but are now almost extinct.

† See Maps of the Geological Survey, 43, S.E. and S.W., and Mr. Sopwith's large map in the Museum of Practical Geology.

the coal-field the eye rests upon the Vans of Brecon, 2,700 feet in height, and the ranges which mark the northern bounds of the great South Wales coal-field. The limestone ridge on which you stand is cut into lofty cliffs lining the gorge of the Wye, and in its extension southwards towards Chepstow, produces those remarkably terraced cliffs which render the scenery of that part of the river as beautiful as it is peculiar.

The area of the coal-field is about 34 square miles. It contains 31 seams of coal, of which only 8 are of a thickness of 2 feet and upwards; and the total series, as stated by Sir H. de la Beche, is as follows:*—

1. Coal-measures with 31 coal-seams ..	2,765	feet
2. Millstone Grit	455	„
3. Carboniferous Limestone	480	„
4. Lower Limestone Shale	165	„
5. Old Red Sandstone	8,000	„ or more.

In the Carboniferous group there is a decrease by two-thirds in the thickness of the strata as compared with the Bristol district. Over the centre of the basin the strata lie nearly horizontally. On approaching the eastern borders they rise very rapidly, but along the opposite, or western edge, the lower beds spread out considerably, and in consequence have a much larger horizontal range than those higher up in the series. The coals are being gradually worked from the margin of the basin where they crop out, towards the centre where they are deep; on which account it is probable that progressive mining operations will be much hindered by the accumulation of water in the old workings.

* Mem. Geol. Survey, vol. i. p. 203.

Mr. Richard Gibbs assures me of an interesting fact in relation to the strata of this district. He states that along a portion of the south-west side of the coal-field, the Millstone Grit and Limestone are overlapped unconformably by the Coal-measures.

Succession of the Coal-Seams.

	Ft.	In.
Sandstones and shales with thin coals	830	0
Cow Delf	0	8
Strata	91	10
Dog Delf	1	2
Strata	46	9
Smith Coal	2	6
Strata	34	6
Little Delf	1	8
Strata	48	8
Park End High Delf	3	7
Strata	56	0
Starkey Delf (with parting)	2	0
Strata	50	0
Rocky Delf	1	9
Strata :	77	6
Upper Churchway Delf (with partings)	1	11
Strata	34	0
Lower Churchway Delf	1	6
Strata	150	0
Braley Delf	1	9
Strata	430	0
Nag's Head Delf	2	9
Strata	153	0
Whittington Delf	2	6
Strata	137	0
Coleford High Delf	5	0
Strata	124	0
Upper Trenchard Delf	2	0
Strata	72	0
Lower Trenchard, or *Bottom Coal*	1	4

The Forest of Dean in 1859 contained 10 iron furnaces, of which 6 were in blast, producing upwards of 31,750 tons of pig-iron. The ore used is derived from the clay-ironstone of the Coal-measures, from hæmatite extracted from the Carboniferous Limestone, and from other extraneous sources.

The Horse.—In one of the coal-seams, called "Coleford High Delf," there occurs one of those interruptions in the regular course of the strata, which tend to throw much light on the original conditions under which coal was formed, but are an occasion of serious loss and disappointment to the proprietor. River channels filled with sand or clay, traversing coal-seams, occur in almost every coal-field, and are known as "rock-faults," and "horse-backs;" but the case to which I have alluded is so remarkable, and has been so fully investigated, that it will serve as a general illustration of these phenomena in other districts.* The description is by Sir H. De la Beche,† who says—The horse with its branches resembles a channel cut amongst a mass of vegetable matters in a soft condition. It ranges S. 31° E. for a length of two miles, and a breadth of 170 to 340 yards. A number of minor channels communicating with each other and the main channel are named "Lows." Mr. Buddle compares the *horse* to the bed of a river, and the *lows* to smaller streams cutting only a lesser depth. The channels are filled principally with sandstone, which extends over the coal-seam and forms its roof.

* Mr. Jukes has very fully described these *horses* or *rock-faults* in the "Thick Coal" near Dudley, in his "Memoir on the South Staffordshire Coal-field," p. 45.

† Mem. Geol. Survey, vol. i, p. 156.

Resources.

1. Area of coal-field	34 square miles.
2. Greatest thickness of Coal-measures ..	2,760 feet.
3. Number of coal-seams from 2 feet and upwards 8, giving a total thickness of ..	24 "
4. Total original quantity of coal (corrected for denudation)	842 millions of tons.
5. Deduct for loss and quantity worked out one-third, leaving for future use	561 " "

6. This, at the present rate of production of 500,000 tons,* would last for 1120 years.

This result shows, that like the two previously described coal-fields, that of the Forest of Dean is capable of yielding a very much larger supply than is the case at present.†

CHAPTER IV.

COAL-FIELD OF THE FOREST OF WYRE, WORCESTERSHIRE.

A coal-field of about as large a superficial extent as that of the Forest of Dean stretches from the northern end of the Abberley Hills, and spreading out under the Forest of Wyre, ultimately becomes contracted northwards to a narrow band lining the banks of the Severn south of Bridgenorth.

* With this estimate I have been furnished by Mr. L. Brough, H.M. Inspector of Mines.

† My colleague, Mr. Bristow of the Geological Survey, estimates the resources of this coal-field somewhat higher, as he informs me that several coals under two feet in thickness can there be worked at a profit.

The Coal-measures repose on a bed of Old Red Sandstone, consisting of red marls, sandstones, and cornstones (concretionary earthy limestone), and are overlaid by a thick mass of Lower Permian strata, composed of red sandstones and marls with calcareous conglomerates, and marly breccia,* very fully developed, at Enville. This Permian breccia has excited much interest regarding its origin; for Professor Ramsay has shown that it bears a strong resemblance to accumulations originating in glaciers, and spread over the sea-bottom by floating ice, such as that of the Boulder clay of the Glacial epoch. If this theory be correct, a vast change must have come over the climate of these countries between the coal-period and that which immediately succeeds it.

This coal-field has not been fully explored; but as far as is known, the coal-seams which it contains are both thin and of inferior quality. The following series occurs near the western margin, as exhibited in Mr. Aveline's section drawn across this district.†

Section of Coal Strata, Forest of Wyre.

	Feet.	Inches.
1. Sandstone and shale	76	0
2. Coal	1	10
3. Sandstone and shale	24	0
4. Coal	2	0
5. Sandstone and shale	39	0
6. Coal	4	0
7. Sandstone, shale, &c.		

* "Breccia" is a word used to designate strata formed of angular pebbles, "conglomerate" being confined to strata where the pebbles are rounded or waterworn.

† Sections of the Geol. Survey, sheet 50; also Geol. Map, 55, N.E.

At Kinlet the lowest coal-seam in the above section is of good quality, and reaches a thickness of 5 feet.

The strata of which this coal-field is composed represent merely the upper Coal-measures, which seldom contain beds of coal of much value or thickness. One bed, however, varying from 4 to 5 feet, has been traced by Mr. G. E. Roberts over a considerable extent of the central part of the coal-field, and is represented in the section below. The absence of the central and lower portion of the formation may be accounted for on the supposition, that this part of England was dry land till near the close of the Carboniferous epoch.

Mr. Roberts has brought to light several very interesting particulars regarding the fossils, both animal and vegetable. In a band of limestone, apparently synchronous with that in the upper Coal-measures of Coalbrook Dale, Warwickshire, and elsewhere, he has found fish-teeth and scales, *Cythere* (*Cypris*) *inflata*, *Spirorbis carbonarius*, and fine specimens of *Posydonia*, determined by Mr. Rupert Jones. But perhaps the most interesting palæontological objects obtained by Mr. Roberts, are specimens of *Pecopteris* and other ferns retaining their fructification.*

At Arley Colliery, near Bewdley, the strata have been penetrated to a depth of 454 yards, ultimately reaching a mass of basaltic rock. Only one workable coal, at a depth of 176 yards, appears to have been found.

* For fuller details see Mr. Roberts' "Rocks of Worcestershire."

The Coal-fields of the Clee Hills, Salop.

Two small outlying coal-tracts, remnants of a formation which once spread continuously from South Wales and Gloucestershire, are perched on the summits of the Titterstone and Brown Clee Hills in Shropshire, at a height in the latter case of 1780 feet above the sea, and if lighted up with the combustible materials with which they are stored, would serve as beacon-fires for many a mile around.

These coal-fields are rather more than a mile each in diameter, and are capped by a bed of hard basalt, to which, owing to its power of resistance to marine denudation, the hills probably owe their preservation. On these flat-topped hills are planted several small collieries, whose shafts pierce the basalt before entering the coal. The vent from which this igneous rock has been erupted is situated in the Titterstone Clee Hill; and from this orifice the basalt has apparently been poured forth in the form of liquid submarine lava, at some period after the Coal-measures were formed.* The thickness of the coal formation is but small, containing only two or three thin coal-seams, and the strata rest generally directly on Old Red Sandstone; but representatives both of the Carboniferous Limestone and Millstone Grit are interposed at the eastern side of the Titterstone Hill.

I have referred to these districts more on account of their geological interest, than for any economical value they may be supposed to possess.

* See horizontal section of the Geological Survey, sheet 36.

CHAPTER V.

SHREWSBURY COAL-FIELD.

THIS coal-field forms a narrow band extending from the base of Haughmond Hill, east of Shrewsbury, to the banks of the Severn near Alberbury, a distance of about 18 miles. Like the coal-field of the Forest of Wyre, the coal-strata repose on the older rocks without the intervention of the Millstone Grit and Carboniferous Limestone; but in this instance the fundamental rocks belong to the Cambrian and Lower Silurian periods. Notwithstanding its length it is seldom more than a mile in breadth; and in its lower part contains two or three coal seams which have been worked to a small extent, but are not of sufficient value to induce mining operations far from the outcrop.

The Coal-measures are overlaid by Lower Permian strata, consisting of red and purple marls and sandstones, surmounted at Alberbury and Cardeston by a remarkable stratified breccia,* composed of angular fragments of white quartz, and Carboniferous Limestone cemented by calcareo-ferruginous paste. The "Alberbury breccia" may be regarded as the remnant of an old shingle beach formed round a coast-line, composed of Carboniferous and Silurian rocks.

In the upper part of this coal-field a band of lime-

* Sir R. I. Murchison, "Silurian System," p. 63.

stone* occurs with estuarine and marine organisms, some of which were at first supposed to be of fresh-water origin. It contains a small crustacean *Cythere*, a bivalve shell, *Anthracosia*, and an annelide, *Spirorbis carbonarius*. Now it is a remarkable instance of the persistency of some calcareous strata over large areas, that this band of limestone, seldom more than a foot in thickness, can be traced in the Coal-measures of Coalbrook Dale and the Forest of Wyre southward, of Lancashire northward, and of Warwickshire eastward, representing an area of about ten thousand square miles; and throughout this expanse it is always found associated with those uppermost coal-strata, which preceded the introduction of the Permian rocks.

The coal-fields of the Forest of Wyre, the Clee Hills, and Shrewsbury, together with a fourth district extending from the base of Caer Caradoc to within a few miles south of Shrewsbury, are of so valueless a nature in regard to their coal deposits, that I do not consider it necessary to attempt an estimate of their resources. They have all been formed in the vicinity of old land-surfaces, and around lines of coast composed of more ancient rocks. The strata themselves belong generally to the higher part of the coal-series, which throughout England is but sparingly enriched with beds of coal.

* This limestone is described by Sir R. I. Murchison ("Siluria," p. 321.)

CHAPTER VI.

COAL-FIELD OF COALBROOK DALE, SHROPSHIRE.

This coal-field has a triangular form, with its base in the valley of the Severn, near Coalbrook Dale, and its northern apex at Newport. Along its western side it is bounded partly by a great fault, which brings in the New Red Sandstone, and partly by the Silurian rocks of the Wrekin, which rises with its smooth and arched back to a height of 1320 feet above the sea, and half that amount above the general level of the country around. Along its eastern side the coal-field is bounded by Permian strata, under which the Carboniferous beds appear to pass, but diminished both in thickness and in productiveness of coal.

The general dip of the strata is eastward; and in making a traverse to the foot of the Wrekin, we cross in succession the base of the Coal-measures, the Millstone Grit, Carboniferous Limestone, a bed of basalt, and at length reach the Silurian rocks which form the general foundation to the Carboniferous formations in this district. This succession of strata is illustrated by the section. (Fig. 8.)

This coal-field has been mapped and described by the Geological Surveyors,* and is the subject of an elaborate memoir by Mr. Prestwich, published in the Geological

* Geological Maps, 61 N.E., and Section Sheet, 54, 58.

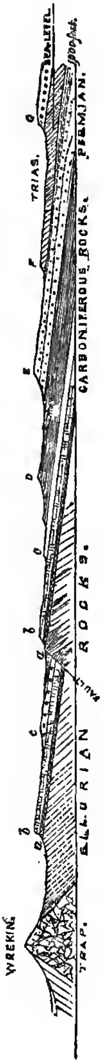


Fig. 8.—SECTION ACROSS THE COAL-FIELD OF COALBROOK DALE.

Distance about 5 miles.

WEST. EAST.

D. Coal-measures, with coal.
c. Millstone Grit.
b. Carboniferous Limestone.
a. Basalt.

E. Permian Rocks,
F. G. New Red Sandstone. { G. Conglomerate. F. Lower Mottled Sandstone

Transactions.* The strata are remarkable for the variations they undergo within narrow limits—some beds rapidly disappearing, or changing their characters. Along the eastern borders the higher strata consist of calcareous breccias and gravels, resembling volcanic ashes, mixed with reddish mottled clays. The coal-seams are also more than usually subject to change; and towards the eastern border, where they pass under the Permian strata, several of the upper coal-beds die out along a gently sloping plane; this is probably due to a cause assigned by Mr. Marcus Scott, who considers that the lower beds with coal have been upheaved and partially denuded before the upper Coal-measures were deposited over them.† It is satisfactory, however, to learn, that in the new colliery belonging to Lord Granville, which passes through about 40 yards of Permian strata, the

* 2nd Series, vol. v.

† From a communication made to the Geol. Society, April 1861

coal-seams have been found at their proper depth and thickness, as far as the sinking has yet been carried—316 yards. If the coals should be found persistent under the Permian rocks, there is a large area beyond the borders of the coal-field itself, where they may be reached at depths under 2000 feet.

The strata of this coal-field are much broken by faults. The largest of these is the western boundary fault; another, the *Lightmoor fault*, traversing the centre of the coal-field from north to south, has a "throw" of about 100 yards: west of this fault the coal-beds are almost exhausted. There are also many transverse fractures.

Organic Remains.—These are extremely varied, and have been enumerated in detail by Mr. Prestwich. They occur principally in the ironstones, of which the principal depositories are the Penneystone and Crowshaw bands. Fish: *Hybodus, Gyracanthus formosus, Cochliodus, Megalichthys Hibberti, Pleuracanthus.* Crustacea: *Limulus*, a genus allied to the king-crab; *Glyphea, Cypris*, or *Cythere inflata.* Mollusca: *Nautilus, Orthoceras, Bellerophon, Conularia, Spirifer bisulcatus, Productus scabriculus, Aviculo-pecten, Anthracosia* (Unio), *Ctenodonta* (or *Nucula*), *Lingula, Rhynchonella.* Insects: one or more species of scorpion; two beetles of the family *Curculionidæ*, and a neuropterous insect, resembling the genus *Corydalis*, and another related to the *Phasmidæ*.*

There are several courses of ironstone measures, which in 1859 yielded 149,480 tons of pig-iron, from 30 blast-furnaces;† the Coalbrook Dale and Lilleshall companies being the largest producers.

* Lyell, "Elem. Geol.," p. 388. † "Mineral Statistics," 1859.

The coal under a very large portion of this field has been nearly exhausted, as will be apparent to any one who crosses it by the Wolverhampton and Shrewsbury railway, where, over a large area, nothing but dismantled engine-houses and enormous piles of refuse from abandoned coal and iron mines meet the eye. The collieries have gradually migrated from the western outcrop towards the east. Under these circumstances, it is probably within the mark to deduct from the original mass of coal two-thirds for the quantity already worked out. Nearly 20 years back, when Mr. Prestwich was engaged in his survey, the district west of the Lightmoor fault was almost destitute of coal.

Resources.

1. Area of the coal-field	28 square miles.
2. Greatest thickness of Coal-measures ..	1,200 feet.
3. Number of coal-seams of upwards of 2 feet, in thickness, 6, giving a total thickness of	27 feet of coal.
4. Original quantity of coal (corrected for denudation.)	43 millions of tons.
5. Total quantity worked out and lost, about 28 millions, leaving for future use ..	15 " "

Which at the present rate of consumption of 765,750 tons (1859) would be exhausted in about 20 years.

This estimate only applies to the actual coal-field. As already stated, the Coal-measures dip under Permian and New Red Sandstone along the eastern margin, and already have these rocks been invaded by at least one coal-shaft, which will speedily be followed by others, should the coal-beds prove continuous—but of this there are at present some doubts.

CHAPTER VII.

THE COAL-FIELDS OF NORTH WALES.

General Structure.

An interrupted tract of Coal-measures extends from the northern slopes of the valley of the Severn, south of Oswestry, to the mouth of the estuary of the river Dee, in Flintshire, crossing the river at the entrance to the Vale of Llangollen. The Coal-measures are overlaid by Permian strata on the south, and New Red Sandstone on the north, and repose on beds of Millstone Grit and Carboniferous Limestone, each about 1000 feet in thickness. These form a range of lofty hills with terraced escarpments looking westward, and exhibit a very noble and striking feature when viewed from behind Llangollen, where they assume the form of a long line of ramparts, the strata being piled like lines of masonry, tier above tier. This rampart forms the physical line of demarcation between Wales and England, though the conventional boundary extends into the plain along the eastern slopes.

These calcareous hills are frequently traversed by faults, and are full of lodes rich in argentiferous galena; the most remarkable of which is the "Great Minera vein," coinciding with a line of fault traversing the Denbighshire coal-field from south-east to north-west, and which in 1857 yielded 2496 tons of ore.

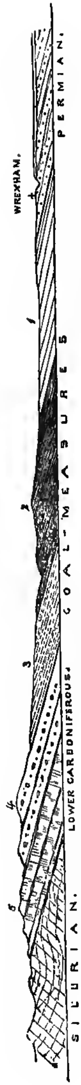


Fig. 9.—SECTION ACROSS THE DENBIGHSHIRE COAL-FIELD.
Length about 6 miles.

1. Upper Coal-measures without coal. 2. Middle Coal-measures with coal. 3. Lower Coal-measures with thin coals. 4. Millstone Grit. 5. Carboniferous Limestone.

The coal-fields here described form part of the counties of Denbigh and Flint: and north of the valley of the Alyn become separated into two portions, by the upheaval along the line of a great fault of the Lower Carboniferous Rocks.* The tract south of this fault is called the Denbighshire coal-field; that to the north, the Flintshire coal-field—each of which will now be described separately.

DENBIGHSHIRE COAL-FIELD.

This coal-field commences about three miles south of Oswestry, where the New Red Sandstone begins to rest directly on the Millstone Grit, and extends northward by Oswestry, Ruabon, and Wrexham, to the north of the valley of the Alyn, which winds through a deep defile, and exposes in its banks an almost complete section of the coal-formation. The length of the coal-field is about eighteen miles; and it is

* This is one of the largest faults in Britain, and has been traced from the sea on the coast of Merionethshire, through Bala Lake into Cheshire. See maps of Geological Survey, sheet 74, N.E. and S.W.

about four miles in breadth at Wrexham, where crossed by the section. (Fig. 9.)

The general succession of the strata is as follows:—

			Thickness.
1. Trias, or New Red Sandstone.			
2. Lower Permian rocks			1,000 to 2,000 ft.
3. Coal-measures	1. Upper series,	1,000 feet	2,800 to 3,000 „
	2. Middle (with coals)	800 „	
	3. Lower (thin coals)	1,000 „	
4. Millstone Grit			800 to 1,000 „
5. Carboniferous Limestone			1,000 to 1,500 „

The Lower Permian strata consist of red and purple marls and sandstones, and may be seen along the banks of the Dee west of Overton, and in the brook which flows eastward of Wrexham.

The Coal-measures may be classed under three divisions. The upper consists of red and grey sandstones and reddish clays, and contains only a few very thin and worthless coals: of these beds there are good sections along the banks of the Alyn, west of Gresford. The middle series constitutes the coal-bearing strata, and contains the following coal-seams of good quality, besides several others not worth mentioning: this series corresponds, with slight variation, to that in Flintshire.

Succession of Coal-Seams, Denbighshire Coal-Field.

Upper and Lower sulphureous coals—not worked.

	ft.	in.		ft.	in.
1. Smith Coal	2 ft.	2 in.	to	2 ft.	4 in.
2. Drowsall Coal (good quality) ..	3	0			
3. Powell Coal	3	3			
4. Two-yard (with "Ribbon" coal under)	5	0	to	6	0
5. Crank Coal (brassy ironstone measures occur here) ..	2	8	to	3	0
6. Brassy Coal (Black-band ironstone occurs here)	5	0			
7. Main Coal	6	0	to	7	6
Total thickness of coal	27	1	to	30	1

The lower measures contain several coal-seams, varying from 2 to 3 feet, which have been but little sought after in the presence of the thick seams from the middle series.

There are several valuable beds of ironstone, the principal being "the brassy" and "black-band," from which in the year 1859, 38,822 tons were raised for the Brymbo and Frood furnaces.

The remains of fish are abundant in this coal-field, and have been classed by Sir P. Egerton under the following genera: *Rhizodus*, *Cœlacanthus*, *Platysomus*, and *Palæoniscus*. The black-band ironstone is very full of fish-scales, teeth, &c., and also contains a bivalve shell of the genus *Anthracosia*. In the Lower Coal-measures the black shales contain *Goniatites* and *Aviculo-pecten*, as is the case in Lancashire and Yorkshire.*

Though containing coal-seams of good quality, and reaching thicknesses of 7 feet, there is a large tract lying between Brymbo and Ruabon over which the coal lies perfectly undisturbed; nor have the coals been followed to any great depth, one of the deepest collieries being only 173 yards.† I think, therefore, I am justified in placing the quantity already worked out at only 1-10th of the whole.‡

* For this information I am indebted to Mr. E. Binney.

† Westminster Colliery.

‡ I am confirmed in this estimate by Mr. Beckett, of Wolverhampton, who is well acquainted with this and the adjoining coal-fields.

Resources.

1. Area of the coal-field	47 square miles.
2. Greatest thickness of Coal-measures	3,000 feet.
3. Number of coal-seams above two feet, 7, giving a thickness of	30 „ of coal,
4. Original quantity (corrected for denudation)	727 millions of tons.
5. Deduct for quantity worked out 1-10th, and for loss 1-4th, leaving for future use	490 „ „

6. Which at the present rate of production of 1,038,500 tons (1859) would last for 470 years.

It is interesting to observe that the produce of this coal-field is nearly double what it was in 1857. In the first edition of this treatise, I stated that the drain was so disproportionate to the great resources of this coal-field, that the supply would last for 930 years at the rate of production for the year 1858—amounting to only 527,000 tons. I also made the following observations—"This result shows what is the fact, that the quantity of coal raised in this coal-field is far below that which it is capable of producing. Collieries are, however, now being erected along the Chester railway, and in a few years the production will probably be doubled. The great depth of the "Drift" accumulations (sand, gravel, and clays) has operated to keep this coal-field partially concealed."

In referring, therefore, to Mr. Hunt's return for the year 1859, I was somewhat startled to find my anticipations of the rapid increase of production so speedily verified; and I have little hesitation in predicting a still further increase in the quantity of coal to be annually raised in Denbighshire.

The quantity above estimated is included within a maximum depth of 2000 feet; a depth of 4000 feet would embrace a band of country containing above one-half more.

The number of collieries in this coal-field, in 1859, was 39.

CHAPTER VIII.

FLINTSHIRE COAL-FIELD.

THIS coal-field is disconnected with that of Denbighshire by the upthrow of Carboniferous Limestone and Millstone Grit over a small tract between Gresford and Hope. From this it extends along the western side of the estuary of the Dee to Point of Aire, a distance of 15 miles; but throughout a considerable part of its range the productive portion is very narrow, and greatly broken by faults.

The general dip of the beds is towards the north-east, and there is no doubt but that they underlie the New Red Sandstone of the Cheshire plain; for they actually reappear on the Cheshire coast at Parkgate, where they are upheaved along a line of fault.*

* Map of the Geol. Survey, 79, N.E. Also Section Sheet 43, with description. For much information regarding this coal-field I am indebted to Mr. Beckett, of Wolverhampton.

The following is the general section of this coal-field:

	Ft.	In.
1. *Four-foot Coal* { Coal / Cannel } ..	4	0
Strata	41	0
2. *Bind Coal*	2	6
Strata with ironstone	62	0
3. { *Hollin Coal* (in three beds)	6	6
Cannel .. .. }	1	6
Strata with ironstone	29	0
4. *Brassy Coal*	3	0
Strata	82	0
5. *Main Coal*	7	0
Strata	180	0
6. *Lower Four-foot Coal* (supposed) ..	4	0

It will be observed that the *Main* and *Brassy* coals of Flintshire and Denbighshire correspond; that the "Hollin" coal of the former is the "Two-yard" coal of the latter, while the "Powell" coal represents the "Bind" coal. The intermediate ironstone-measures also correspond. The "Lower four-foot" coal in the Flintshire section cannot yet be said to have been satisfactorily determined. The general quality of the coal is excellent.

In the Lower Coal-measures, below all the strata above named, Mr. Binney informs me that there are several thin seams with roofs of black shale, containing *Goniatites* and *Aviculo-pecten*, corresponding to the Gannister coals of Lancashire and Yorkshire. These coals are visible in a brook section south of Hope, which in another part displays very beautifully the unconformable superposition of the New Red Sandstone on the Lower Coal-measures.

The strata of the Flintshire coal-field rarely attain a great depth. If we cross the centre of the district from west to east, we find the beds repeatedly upheaved along dislocations ranging north and south. The result is, that the greater portion of the coal being placed so near the surface has already been exhausted, and probably not more than one-half remains for future use. The valley of the Dee seems to offer favourable positions for deep shafts; and already the coal is being won under high-water mark on Mostyn Bank.

There can scarcely remain a reasonable doubt of the continuation of the coal-formation from Flintshire to Lancashire and Staffordshire under the intervening tract of New Red Sandstone.

Resources.

1. Area of the coal-field	35 square miles.
2. Number of coal-seams at least 5, giving a thickness of	25 feet of coal.
3. Original quantity (corrected for denudation) ..	54 millions of tons.
4. Quantity raised, one-half; ditto spoiled, and lost 1-10th; leaving for future use	21 " "

5. At the present rate of production of 587,500 tons (1859), the coal-field would be exhausted in about 40 years.

This coal-field contains 37 collieries.

CHAPTER IX.

ANGLESEA COAL-FIELD.

Crossing a mountainous region of 45 miles in breadth from the Flintshire coal-field to the centre of Anglesea, we find a series of Carboniferous strata on the whole similar to those just described.

The Anglesea coal-field forms a band of country stretching from Hirdre-faig to Malldraeth Bay, a distance of nine miles. Its breadth at Malldraeth Marsh is a mile and a half. The Coal-measures are overlaid uncomformably by red sandstone, conglomerate, and marl, of Permian age, and from beneath the coal-strata the Millstone Grit and Carboniferous Limestone rise in succession, their base resting on highly-contorted and metamorphic schists of Cambrian or Lower Silurian age. The existence of this coal-tract is entirely due to an enormous fault, having at one point a down-throw on

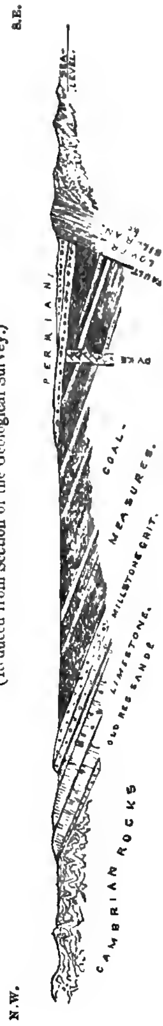


Fig. 10.—SECTION ACROSS THE ANGLESEA COAL-FIELD.
(Reduced from Section of the Geological Survey.)

the north-west of 2300 feet. Through its agency the Carboniferous strata, have been dropped down, and are protracted on all sides by the ancient Silurian rocks. (See Section 10, page 105.)

The following is the general succession of the strata as determined by Professor Ramsay.*

Succession of Strata, Anglesea Coal-Field.

		Ft.	In.
Permian Rocks—	Red sandstone, marl and conglomerate	195	0
Coal-measures—	*Coal* ("Glopux") lying in lumps ..	9	0
1309 feet.	Shale	51	0
	Coal	3	0
	Shale	63	0
	Coal	4	0
	Strata	75	0
	Coal (irregular)	2	0
	Strata	43	0
	Coal	6	0
	Strata	90	0
	Coal (with cannel roof)	1	8
	Strata (about)	300	0
	Coal (supposed Berw Uchaf coal, in 3 beds with partings ..	7	6
	Strata	650	0
Millstone Grit	*Coal* (perhaps in Millstone Grit) ..	2 to 3	0
	Yellow sandstone and Conglomerate ..	200	0
Carboniferous Limestone.	Gray and black limestone, and sandstone, with *Productus*, *Spirifer*, Corals, &c.	450	0

Some of these coal-seams crop up against the base of the Permian strata, proving the great discordance between the formations. A greenstone dyke rises in a line of fault near Berw colliery, but appears not to enter the Permian strata.

* See description of Horizontal Section of the Geological Survey, sheet 40; also Geol. Map, sheet 78.

Another small coal-tract lines the banks of the Menai Straits near Carnarvon.

In 1857 the Anglesea coal-field contained five collieries, producing about 4500 tons of coal. In 1859 the same number of collieries produced 35,000 tons.

CHAPTER X.

SOUTH STAFFORDSHIRE COAL-FIELD.

THIS coal-field extends from the Clent Hills on the south to Brereton, near Rugeley, on the north, a distance of 21 miles, and is of an average breadth of seven miles. It appears to have been upheaved bodily along two great lines of fracture, which range in approximately parallel directions from north to south. Beyond these lines, Permian and Triassic rocks set in.

Aspect of the Coal-field.—This district is one of extreme productiveness in coal and iron ; and its proximity to the towns of Wolverhampton, Dudley, and Birmingham, has imparted an extraordinary impetus to these foci of industry. But indeed it may be said, that the whole line of country connecting these towns, a distance of 12 miles, forms one great workshop : and on a fine night, the spectacle from the walls of Dudley Castle, which rises from the centre of the coal-field, is one which has scarcely a parallel. The whole country within a radius of five or six miles is overspread by collieries, iron-foundries, blast-furnaces, and the dwellings of a

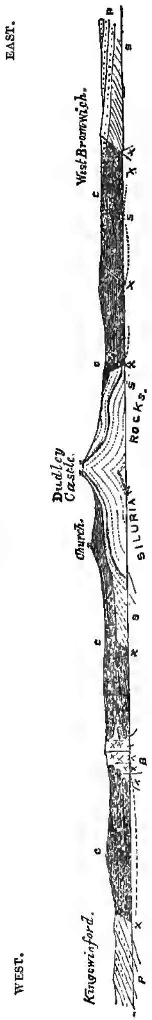


Fig. 11.—SECTION ACROSS THE SOUTH STAFFORDSHIRE COAL-FIELD.
Distance about 6 miles.

× Faults. B. Basalt. S. Upper Silurian Rocks. C. Coal-measures. P. Permian Rocks.

dense population; and from amidst the thick smoky atmosphere, the tongues of fire from the furnaces shoot up an intermittent light which illuminates the whole heavens. But the spectacle before our eyes does not represent the whole sum of human labour; for whilst ten thousand hands are at work above ground one-half as many, perhaps, are beneath the surface, hewing out the coal which is to be the prime-mover of the whole machinery.

Physical Geology.—It has been shown by Mr. Jukes,* that while the Lower Carboniferous rocks were being deposited over other parts of England, a band of country stretching from Shropshire across South Staffordshire and Warwickshire was dry land; consquently there is no Carboniferous Limestone or Millstone Grit, and the Coal-measures repose directly on an eroded surface of upper Silurian rocks, which at Sedgley,

Note.—The Section at the side of the page is reduced from one by Mr. Jukes.

* "South Staffordshire Coal-field," Mem. Geol. Survey, 2nd Edition, (Preface.) See Geol. Maps, 62 S.W., 62 N.W., and corresponding Sections.

Dudley, and Walsall, rise from beneath the Coal-formation. (See Section, Fig 11.)

The general succession of the strata, as given by Mr. Jukes, is as follows :—

		Ft.
Trias—Bunter Sandstone 1,200	1. Upper mottled sandstone ..	500
	2. Conglomerate beds ..	500
	3. Lower mottled sandstone ..	200
		1,200
Permian [Lower Division] 1,000 to 3,000	1. Breccia of felstone, porphyry, & Silurian rocks 2. Red marls, sandstone, & calcareous conglomerate	1,000 to 3,000

Coal-measures—Southern district.

		Ft.
Upper Coal-Measures—1,300	Red and mottled clays, red and grey sandstone and gravel beds	800
Middle Coal-Measures—510 ..	1. *Brooch Coal*	4
	Strata, with ironstone	130
	2. *Thick Coal*	30
	Strata with "Gubbin ironstone" ..	20
	3. *Heathen Coal*	4
	Strata with ironstone	109
	4. *New Mine Coal*	8
	Strata with ironstone	16
	5. *Fire-Clay Coal*	7
	Strata	30
	6. *Bottom Coal*	12
	Strata with several courses of ironstone	140
Upper Silurian Rocks—	1. Ludlow rocks, with Aymestry limestone.	
	2. Wenlock and Dudley Limestone and Shales.	
	3. Woolhope Limestone (?)	
	4. Llandovery Sandstone.	

Coal-seams.—From the above list it will be seen, that in the Dudley district there are six workable seams of coal, giving a total thickness of 65 feet. The most remarkable of these is the "Ten-yard," or "Thick coal," of a general thickness of 30 feet and a source of enormous wealth to the district. It underlies a large area, at a moderate depth; and has either been worked out, drowned, or destroyed to such an extent, that probably little more than one-tenth remains to be won. It is rather subject to "rock-faults," or "horse-backs," instances of which are given by Mr. Jukes;* and the author has seen an instance at Baremoor colliery, where the whole mass of coal has been replaced by sandstone—the junction being formed of a series of interlacings.

Thinning of the Strata southwards.—In the northern part of the coal-field, at Essington and Pelsall, this massive bed becomes split up into nine distinct seams, with a combined thickness of exactly 30 feet of coal; but separated by 420 feet of sandstones and shales, all of which are absent to the south of the "Great Bentley fault." This remarkable thinning out of the strata takes place in a distance of five miles from north to south, and is an additional instance of the vastly higher amount of persistency in the coal-seams than in the sedimentary strata with which they are associated.

Dip of the Beds.—North of the Great Bentley fault, the general dip is from east to west; and there is an extensive tract of about ten miles in length extending to Beaudesert, and three in breadth, over which the lower coal-seams lie undisturbed, as those which are worked at Essington and Wyrley occupy a higher position. At Brereton there are several shafts sunk through Con-

* "South Staffordshire Coal-field," &c., p. 45 et seq.

glomerate beds of the New Red Sandstone, under which formation the coal is extensively worked.

TRAP ROCKS.

Basalt.—In several localities over the southern portion of the coal-field, several varieties of igneous rocks are found, frequently burrowing through and altering the Coal-measures, and sometimes resting upon them. The finest exhibition is the basaltic mass of Rowley Regis, or "Rowley rag," forming a hill about two miles in length, and 820 feet in height. This basalt assumes the columnar structure, affording examples of prisms as perfect as those from the Giant's Causeway in Ireland. Mr. Jukes considers that this rock has been poured out in the form of a lava-flow, during the coal period; for the beds of coal dip under the basalt, and have been followed till found "blackened," or charred, and utterly worthless.*

At Pouk Hill, near Walsall, is another mass of columuar basalt, in which there are vertical, horizontal, bent, and radiating columns.

Greenstone.—In the Lower Coal-measures, a sheet of greenstone spreads almost without interruption from the base of Rowley Regis, through the centre of the district, to Wolverhampton, Bilston, and Bentley. This would appear to have been a lava-flow of earlier date than the basalt, but ejected from the same vent, which we may suppose to be situated near the centre of the hill. There are also beds of volcanic ashes and gravel associated

* "South Staffordshire Coal-field," &c., p. 120.

with the Upper Coal-measures at Hales Owen, probably nearly contemporary in their formation with the Rowley basalt.

Ironstones.—The ironstones occur in beds, associated with shale, and are the principal repositories of the fossils. The principal bands are :—

1. The Pins and Pennyearth ironstone-measures.
2. The Grains ironstone } below the Thick Coal.
3. The Gubbin ironstone } below the Thick Coal.
4. The New Mine ironstone.
5. The Pennystone do., with marine fossils, *Producta, Avicula-pecten, Lingula*, &c., a *Palechinus*, and fish-teeth and bones.
6. Poor Robin, and White ironstone—only local.
7. Gubbin and Balls ironstone.
8. Blue Flats, Silver Threads, and Diamond ironstone.

Fossils.—Fish : *Gyracanthus formosus* (ichthyodorulites), *Rhizodus, Pleurodus, Ctenoptychius, Megalichthys Hibberti, Cochliodus, Pœcilodus.* Molluscs : *Productus, Conularia, Lingula, Myalina, Anthracosia acuta* (in coal), *Aviculo-pecten scalaris ;* Annelides ; and the usual Coal-measure plants.*

Resources.

In order to arrive at an estimate of the resources of this coal-field, it is necessary to consider the northern and southern halves separately ; as the former contains about three-fourths of the original quantity of coal, the latter only one-tenth.

1. Area of coal-field	93 square miles
2. Average thickness of workable coal above 2 feet	16 yards.

* These fossils have been determined by Mr. Salter, of the Museum of Practical Geology. They are similar to those of the "Penneystone" band of Coalbrook Dale.

3. Total original quantity of coal (corrected for denudation)	3,072	millions of tons.	
4. Of this, the Northern part contained ..	1,024	„	„
Deduct 1-4th, leaving for future use ..	768	„	„
5. The Southern part (south of the Bentley fault) contained	2,048	„	„
Deduct 9-10ths, leaving about	205	„	„
6. Total quantity remaining (768+205) ..	973	„	„

Which at the present rate of consumption would be exhausted in about 210 years.

In 1859 there were in the South Staffordshire coal-field, 422 collieries; at which 4,450,000 tons of coal, and 825,000 tons of ironstone, were raised. The average production of iron from this ore being 33 per cent.

The number of furnaces in blast in the district was 123; in which 475,300 tons of pig-iron were smelted in 1859, and 597,809 tons in 1858.*

CHAPTER XI.

NORTH STAFFORDSHIRE COAL-FIELD.

THE North Staffordshire coal-field, though of smaller area than that of South Staffordshire, has vastly greater capabilities. The strata are about four times as thick, with twice the thickness of workable coal; and instead of being bounded on each side by an enormous fault, which at one step places the coals at almost unapproachable depths, the Coal-measures of North Staffordshire dip under the Permian and Triassic rocks along a

* "Mineral Statistics," 1858 and 1859.

Fig. 12.—GENERAL SECTION ACROSS THE NORTH STAFFORDSHIRE COAL-FIELD.

1. New Red Conglomerate. 2. Permian rocks. 3. Upper Coal-measures. 4. Middle Ditto, with Coal. 5. Lower Coal-measures, with thin Coals. 6. Millstone Grit.

line of many miles at the south-western border of the coal-field, and under these formations coal may be obtained at a future day. Moreover, there are none of those protrusions of igneous rocks which have produced so much injury to the coal-beds near Wolverhampton, Dudley, and Hales Owen. This coal-field has the shape of a triangle, with its apex to the north at the base of Congleton Edge; the eastern side is formed of Millstone Grit, and the westerly of New Red Sandstone or Permian strata. Along the south the Coal-measures are overlaid by Permian marls and sandstones, and these strata run far up into the heart of the coal-field by Newcastle, along the line of a great fault, which ranges north-north-west towards Talk-on-the-Hill.*

On that division of the coal-field extending eastward of this tongue of Permian rocks are situated the Potteries, a group of populous towns, from which all parts of the world are supplied with china-ware rivalling that of Dresden, with vases and various kinds of vessels modelled after Etruscan patterns, but adorned

* Geological Survey, Map 72, N.W.

with paintings from natural models, executed with a perfection of colouring and outline to which the Etruscans never attained; here also are produced those tesselated pavements which adorn so many of our churches and public buildings. For the production of these works of art chalk-flints are brought from the south of England, decomposing granite from Cornwall, gypsum from Chellaston, siliceous chert from Derbyshire. The coarser kinds of earthenware and tiles are made in large quantities from the clays of the Upper Coal-measures, and the coal supplies the heat for the baking ovens.

*Succession of Strata, North Staffordshire Coal-field.**

		Greatest thickness. Feet.
Permian Rocks	Red and purple sandstone, marl, and cornstones (with plants), strata slightly unconformable to the coal-measures	600
Coal-measures—5,000 feet.	1. *Upper*—Brown sandstones, greenish conglomerate (like the volcanic ashes of S. Staffordshire) with thick beds of red and purple mottled clays; thin coals ..	1,000
	2. *Middle*—Sandstone, shales, with ironstone, and about 40 coal-seams	4,000
	3. *Lower*—Black shales and flags, with Wetley Moor thin coals. (*Goniatites, Pecten.*)	1,000
Millstone Grit	Coarse grits, shales, and flags ..	4,000
Yoredale Rocks	Black shales, &c., with marine fossils	2,300
Carboniferous Limestone	.. ..	4,000 to 5,000

If we compare the above section with that of South

* See Horizontal Sections of the Geological Survey, Sheets 42 and 55, with Explanations. This coal-field was surveyed by Mr. W. W. Smyth, and the author, in 1856-7.

Staffordshire we cannot but be struck with the vast accession of sedimentary materials in this northerly direction.

Succession of Coal-Seams.

	Ft.	In.		Ft.	In.
1. *Peacock Coal* ..	6	6	12. *Coal*	3	0
Strata	20	0	Strata	270	0
2. *Spencroft*	3	9	13. *Birches' Coal* ..	4	6
Strata (with shells)	121	0	Strata	300	0
3. *Great Row* ..	8	0	14. *Ten-feet Coal* ..	6	0
Strata	71	0	Strata	102	0
4. *Cannel Row* ..	5	0	15. *Bowling Alley* ..	4	6
Strata	54	0	Strata	81	0
5. *Wood Mine* ..	2	0	16. *Holly Lane* ..	5	10
Strata	29	0	Strata .. .	84	0
6. *Deep Mine* .	2	8	17. *Sparrow Butts Coal*	4	9
Strata	361	0	Strata .. .	222	0
7. *Winghay Coal* ..	4	6	18. *Flats*	3	0
Strata ..	377	0	Strata	108	0
8. *Ash* or *Rowhurst* ..	8	0	19. *Frog's Row* ..	4	6
Strata	121	0	Strata	30	0
9. *Burnwood* ..	5	0	20. *Cockhead*	4	6
Strata	68	0	Strata	420	0
10. *Golden Twist* ..	3	6	21. *Bullhurst*	4	0
Strata	486	0	Strata	60	0
11. *Mossfield*	4	7	22. *Winpenny* ..	3	0
Strata	30	0			

Lower Coal-measures, with two thin coals of Wetley Moor. Besides the above there are 15 other seams of little or no value.

Ironstone measures.—This coal-field contains several very valuable bands of ironstone, of which the following are the principal:—1. *Top red mine* of Silverdale, 18 inches thick; 2. *Gubbin ironstone*, which is filled with the bivalve shell *Anthracosia*; 3. *Pennystone*; 4. *Two-feet mine*; 5. *Burnwood ironstone*.

Fossil Remains.—Fish: Messrs. Garner and Molyneux have been collecting with much success specimens of the ichthyolites, which occur in profusion in some of the ironstone bands and their associated shales, the "Bassy mine" being the most prolific. They occur principally in the higher strata of the coal-field, and the following genera are recorded:* *Dipterus* (?),† *Palæoniscus ornatissimus*, *Gyrolepis*, *Cœlacanthus*, *Rhizodus*, *Holoptychius*, *Ctenodus*, *Megalichthys*, *Saurichthys* (?)† *Ctenacanthus*, *Hybodus*, *Diplodus*, *Ctenoptychius*, *Petalodus*, *Helodus*, *Pleuracanthus*, *Onchus* (?), *Orthacanthus* (ichthyodorulites, sometimes 12 inches in length), *Leptacanthus*, *Gyracanthus*. Of Mollusca, the only examples found in the Middle and Upper measures have been nine or ten species of the genus *Anthracosia* which are abundant in some of the ironstones, and in the roofs of some of the coal-seams, especially the *Great Row* seam, as I am informed by Mr. Henry Eaton. In the Lower measures *Aviculo-pecten* and *Spirorbis* (*Microconchus*) *carbonarius* occur. Plants of most of the usual Carboniferous genera are abundant.

Faults.—The faults of this coal-field are not numerous except in the neighbourhood of Talk-on-the-Hill. There are, however, several very large dislocations: one of which forms the boundary of the coal-field along its

* Trans. Brit. Association, 1859, p. 103. These genera (I understand) have been verified by one of our highest authorities, Sir Philip De M. Egerton.

† I have placed a (?) after *Dipterus* and *Saurichthys*, as the former of these genera is generally considered exclusively Devonian, the latter Triassic.

north-western edge. It runs along the western base of Congleton Edge and west of Talk, throwing down the New Red Marl of the Cheshire basin on the north-west against the Carboniferous rocks on the south-east. This dislocation is more than 500 yards, and its direction is north-north-east. Another fault, with a downthrow on the east of 350 yards, passes by Newcastle and east of Hanchurch; and at Hanford there is a third and parallel line, with a downthrow of 200 yards, on the same side. East of Longton the coal-field is bounded by a large fault, which was visible near the entrance to the railway tunnel when it was being made: it throws in the New Red Sandstone on the east side.

Resources.

This coal-field has been worked only to a small extent in comparison with its enormous resources. Yet, that these resources are now being recognised is evinced by the fact, that between the years 1857-59 the quantity of coal raised nearly doubled itself. As the coal-bearing strata are upwards of 5000 feet in thickness, it is evident that in some parts of the district, towards the borders of the Permian rocks, the lower coals can never be reached, so that we must make large deductions (about one-third) for the quantity which is not likely to become available.

1. Area of coal-field	75 square miles.
2. Total thickness of measures	5,000 feet.
3. Number of workable coal-seams, 22, with a thickness of	94 feet of coal.

4. Total original quantity of coal .. 3,600 millions of tons.
5. From this deduct 1-3rd (as above) .. 2,400 " "
6. Deduct for quantity worked out 1-10th; and for waste 1-4th.
7. Leaving for future use .. .. 1,620 " "
Which at the present rate of consumption would last for 740 years

This coal-field contained in 1859 only 127 collieries, raising 2,200,000 tons of coal; a quantity small when compared with the produce of South Staffordshire. We may, however, expect that in future years while the produce from South Staffordshire gradually diminishes, that from North Staffordshire shall constantly increase. I entertain a very high opinion of the resources of this coal-field. It is practically inexhaustible, as it descends to unapproachable depths, while the beds of coal and iron are of the finest description.

In the same year 624,000 tons of iron-ore were raised, nearly half of which was sent into the southern part of the county, and the remainder smelted in 23 blast furnaces, producing 143,500 tons of pig iron.*

CHAPTER XII.

CHEADLE COAL-FIELD, STAFFORDSHIRE.

A SMALL, and but slightly productive coal-field stretches from the valley of the Churnet on the north-east to the hills of New Red Sandstone, which stretch in a picturesque and abrupt semicircle along its southern borders.

* "Mineral Statistics," 1858.

Towards this range the strata dip (S.S.W.), and on the north side of the Churnet the high moorlands of the Millstone Grit rise from beneath the Coal-formation. In the centre of the coal-field, an outlier of New Red Conglomerate reposes unconformably on the Coal-measures, and forms the site of the pretty town of Cheadle. *

The following is the succession of the coal-seams :—

1. Two-yard coal.
2. Half-yard coal.
3. Yard coal.
4. Littley coal.
5. Four-foot coal.
6. Woodhead 3-feet coal.

Hœmatite Bed of Churnet Valley.

The Lower Coal-measures of the Churnet Valley contain two thin coals, one of which has a roof of black shale with *Goniatites* and *Aviculo-pecten.*† Below these there occurs a valuable bed of *iron ore,* which is now being extensively worked along the valley from the outcrop. This iron bed varies from 6 to 20 inches in thickness, is of a deep-red colour, and contains about 35 per cent. of iron. It seems to be in reality but shale highly impregnated with hydrated peroxide of iron.

* See Geol. Survey, Map 72, N.E.. and Horizontal Section, sheet 57, with "Explanation."

† Mr. Binney, Trans. Geol. Soc., Manchester, vol. ii. p. 81.

CHAPTER XIII.

THE LANCASHIRE COAL-FIELD.

THIS great coal-bearing tract is very irregular in outline, and consequently difficult to describe. It may, however, be said to occupy a band of country lying east and west, sending offshoots at intervals into the Trias and Permian formations on the south, and into Lower Carboniferous strata which form its mountainous limits on the north. These offshoots are occasioned generally by enormous faults.

The extreme western boundary is a great fault, which, throwing down the New Red Sandstone on the west side, ranges through Eccleston, Lathom Park, Bickerstaffe, Knowsley Park, and Huyton. To the northward the high moorlands, formed of Millstone Grit and Lower Coal-measures, traversed by deep valleys with scarped flanks, reach elevations of 2,000 feet, and stretch with a semicircular outline from

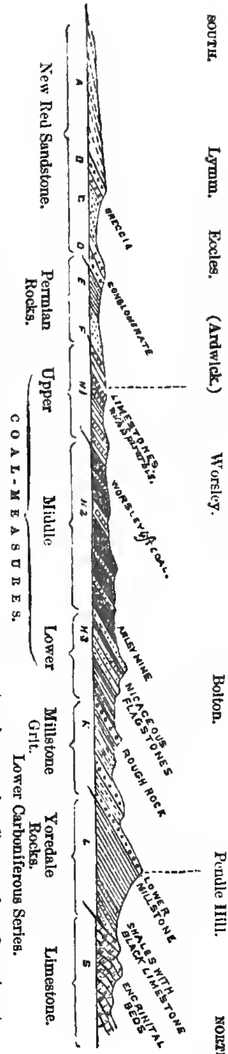


Fig. 13.—GENERAL SECTION ACROSS THE CARBONIFEROUS ROCKS OF LANCASHIRE.

Chorley to Staleybridge, by Bolton, Bury, and Oldham. From this elevated tract the country gradually descends towards the Valley of the Mersey, and the Coal-measures dip under the Triassic and Permian strata, which form the low-lying districts, by Rainford, Newton, Ashton in Makerfield, Leigh, Astley, Eccles, Manchester, and Stockport, near which point the coal-field crosses the Mersey and enters Cheshire. The extreme length from Bickerstaffe to Staleybridge is 32 miles, and the average breadth 6 miles. Smaller isolated coal-fields occur at Croxteth Park, Manchester, and Burnley.

General Succession of Formations.

			Maximum thickness. Feet.
Trias 4,750 ft.	Keuper (A, B, of fig. 13.)	1. Red Marls (Cheshire) ..	.. 3,000
		2. Lower Keuper Sandstone (Waterstones)	.. 500
	Bunter (C. D.)	1. Upper Mottled Sandstone	.. 500
		2. Conglomerate beds ..	.. 650
		3. Lower Mottled Sandstone (often absent)	.. 100
Permian Series 355—650 feet.	1. Upper (E.)	Red marls and limestones of Leigh, Patricroft, Manchester, with *Schizodus*, *Bakevellia*, *Turbo*, *Tragos*, *Rissoa*, *Natica minima*.	.. 250
	2. Lower (F.)	Sandstone of Collyhurst, &c.	.. 100 to 400

Note.—Several valuable memoirs on this coal-field have appeared by Mr. Binney, Trans. Geol. Soc., Manchester, vols. i. and ii., part 7; also by Mr. Bowman—*Ibid.* See also Mr. Dickinson's Vertical Section, in Report of the Inspectors of Mines for 1858. The Geological Survey of Lancashire is now in progress, and partly completed.

			Maximum Thickness. Feet.
Coal-measures 6,800 ft. to 7,300	1. Upper (H 1.)	Shales, sandstones, and limestones of Ardwick, with *Spirorbis*, *Cythere*, and fish of the genera *Ctenoptychius*, *Megalichthys*, *Palæoniscus*, &c.: and a bed of black-band ironstone with *Anthracosia Phillipsii*. Below these beds are sandstones, shales, and thin coal-seams.	1,500 to 2,000
	2. Middle (H 2.)	From the Worsley Four-feet Coal to the Flags below the "Arley Mine," with *Anthracosia*, *Modiola*, fish, &c.	3,500
	3. Lower, or Gannister Beds. (H 3.)	Flags, shales, and thin coals, with Gannister floors, and roofs of shale with *Spirorbis*, *Goniatites*, *Nautilus*, *Avicula-pecten*, *Lingula*, *Anthracosia*, fish, *Cythere* or *Cypris*.	1,800
Millstone Grit	From the "Rough Rock" to the lowest millstone grit (with thin coals) ……..		3,500
Limestone Shale or Yoredale Rocks, with molluscs ….			2,000

The coal-series varies considerably in different parts of the districts, and there is a general thickening of the sedimentary materials, as sandstones and shales, towards the N.N.W. Thus the *same* coal-seams are farther apart at St. Helens than at Prescot, and at Wigan than at St. Helens.

Several coals can be traced over the entire district under different names. The "Little Delf" of St. Helens is the "Arley Mine" at Wigan, the "Riley Mine" of Bolton, and the "Dogshaw Mine" of Bury. It is the lowest coal-bed of the Middle Coal-series, and one of great economic value. Its roof frequently contains fish remains, and some yards above it there occurs a very constant bed of ironstone filled with *Anthracosia* (*unio*) *robusta*. Above this is the "Rushy Park" coal, which is very constant; but unfortunately the most valuable of all the coal seams, the *Cannel Mine* of Wigan, thins away in every direction from Wigan as a centre. The Trencher Bone of Bolton is the Wigan 9-feet, and the Roger 9-feet of St. Helens.

General Section of the Coal-series at St. Helens.

(The numbers show the Coals which correspond to each other.)

	Yards.	Ft.	In.
Strata of Upper Coal-measures without coal	650	0	0
Lyons Delf Coal (inferior)	0	2	8
Strata	16	2	0
London Delf Coal (inferior)	0	2	6
Strata	28	2	2
Potato Delf (inferior)	0	5	0
Strata	14	0	0
Earthy Delf (unworkable, full of partings) .	0	4	8
Strata	94	1	0
St. Helens Main Coal	0	9	0
Strata	10	2	0
Four-feet Coal	0	3	6
Strata	18	2	0
Cannel	0	1	6
Strata	92	2	0
Coal	0	3	10
Clay	1	1	2
Ravenhead Main Coal	0	7	0
Strata	33	0	0

	Yards.	Ft.	In.
Bastions Mine	0	4	3
Strata	4	1	0
Higher Roger Coal (inferior, with partings)	0	4	0
Strata	61	2	0
Flaggy Delf	0	4	0
Strata with Lower Roger Coal	152	2	0
2. *Rushy Park Coal*	0	4	6
Strata	54	0	0
1. *Arley Main or Little Delf*	0	3	0

General Section of the Coal-series at Wigan.

		Yards.	Ft.	In.
	Strata .. .. (about)	100	0	0
15.	*Ince Yard Coal*	0	3	0
	Strata with ironstone	51	0	0
14.	*Ince* Four-feet *Coal*	0	3	7
	Strata	27	0	0
13.	*Ince* Seven-feet (with parting)	0	7	0
	Strata	23	1	0
12.	*Furnace Mine* (with parting)	0	4	7
	Strata	84	0	10
11.	*Pemberton* Five-feet Mine	0	5	2
	Strata (with a coal-seam 2 feet thick) ..	25	1	0
10.	*Pemberton* Four-feet Mine	0	4	6
	Strata	149	0	0
9.	*Wigan* Five-feet (inferior)	0	4	6
	Strata	21	0	0
8.	*Wigan* Four-feet (inferior)	0	4	0
7.	Strata, with a worthless coal called "Nine-feet Mine"	125	0	0
6.	*Cannel* (best gas coal)	0	3	0
	Strata (variable)	1	1	0
5.	*King Coal*	0	3	10
	Strata	79	0	0
4.	*Yard Coal*	0	3	0
	Strata	50	0	0
3.	*Bone Coal*	0	2	3
	Strata	3	0	0
2.	*Smith Coal* (Rushy Park)	0	3	6
	Strata	60	0	0
1.	*Arley Mine* (the most valuable next to the *Cannel*)	0	4	0

General Section between Manchester and Bolton.

(Curtailed from that of Mr. Dickinson.)

	Yards.	Ft.	In.
Upper Coal-measures with 17 beds of Coal, too thin for working	420	0	0
Worsley 4-Feet Coal (good)	0	4	3
Strata, with 25 seams of coal under two feet	294	0	0
15. *Bin Coal* (inferior)	0	3	6
Strata	26	0	0
14. *Albert Mine*	0	3	3
Strata	14	0	0
Crumbourke Coal	0	4	0
Strata	48	0	5
13. *Rams Mine* (good)	0	5	6
Strata, with 2 coal-seams under two feet ..	84	2	7
10 { *White Coal* (good)	0	3	0
10 { Strata (of variable thickness)	7	0	0
10 { *Black Coal*	0	3	0
9. *Old Doe Coal* (3 beds with two partings) ..	0	8	0
Strata	10	1	0
8. *Five-quarters Coal*	0	3	6
Strata (with 3 coals under 2 feet) ..	88	2	0
7. *Trencher Bone Coal* (3 - 6 to 6 feet) ..	0	5	0
Strata	34	0	0
6. *Cannel Mine* (cannel only 6 inches) ..	0	4	6
Strata	19	1	0
5. *Saplin Coal* (with parting)	0	4	0
Strata	35	6	0
Plodder Coal (coal and shale, variable) ..	0	3	0
Strata	38	0	0
4. *Yard Mine*	0	3	0
Strata with 4 thin coals	56	0	0
2. *Three-quarters Mine*	0	2	0
Strata	68	2	0
1. *Arley Mine* (with parting)	3/6 to 4		6

The strata here enumerated are characterized by several bands with *Anthracosia*. From the *cannel*, the late Mr. Peace collected splendid specimens of fishes belonging to the genera *Megalichthys*, *Holoptychius*, *Ctenoptychius*, &c.

The Lower Coal-measures, or Gannister beds, commence with the micaceous flagstones of Up-Holland, and contain six or seven coal-seams, seldom of greater thickness than 2 feet. Mr. Binney has shown that in various parts of the coal-fields all these coals contain *Goniatites*, *Nautili*, *Aviculo-pectens*, &c., in their roofs, species which do not pass upwards into the Middle Coal-measures; at the same time species of *Anthracosia* occur in these same beds at Billinge. The floor of one or more of these lower coals (called sometimes "Mountain Mines," from their occurrence in the uplands) is formed of a very hard siliceous rock called *Gannister*, penetrated by *Stigmaria ficoides*, from which the name, suggested by Professor J. Phillips, has been adopted for the whole series.

In estimating the resources of the Lancashire coal-field, I shall altogether exclude these Gannister or lower coals, as they are too thin ever to admit of mining very far from the outcrop.

Iron Ores.—The Ironstone measures of Lancashire are on the whole very poor, and although formerly used for smelting at Haigh foundry, are not at present so employed.* At Patricroft the Upper Coal-measures yield a valuable calcareous hæmatite 2 feet thick, and

* The blast-furnaces of Kirkless Hall, near Wigan, are the only ones at present erected, I believe, in South Lancashire, and these are supplied with hæmatite ore from Ulverston.

Mr. Binney has identified this same band in the upper beds of the Manchester coal-field.*

Faults.—The Lancashire coal-field is traversed by dislocations which, although of great magnitude, produce scarcely any perceptible features at the surface—so complete have been the effects of denudation in levelling down inequalities arising from the displacement of the rocks. Over the southern portion of the district many of the faults slope or *hade* considerably; the general inclination being 25° from the vertical, but often more.

The western boundary fault of the coal-field is a downthrow on the west of 1,500 yards east of Ormskirk, where the Lower Keuper Sandstone and Lower Coal-measures are brought into contact.

The Great Up-Holland fault, which brings up the Lower Coal-measures so as to form an elevated band of country between the coal-fields of Rainford and Wigan, has a throw of 650 yards east of Lord Crawford's collieries.

The Coal-measures at Wigan are divided into belts, bounded by parallel faults which range N.N.W., having throws varying from 150 to 600 yards; of these the principal are the "Shevington fault," the "Cannel fault of Ince," and the "Great Haigh fault." Towards Manchester there is the "Great Pendleton or Irwell Valley fault," ranging along the valley of the Irwell (N.N.W.), bringing in the New Red Sandstone, with a downthrow on the N.N.E. of upwards of 1000 yards. Lastly, the great fault along which the Manchester coal-

* Trans. Geol. Soc. Manchester, vol. i.

field has been upheaved on the west against the New Red Sandstone; the throw being at least 400 yards. All these dislocations appear to have been produced, or at least *repeated*, after the period of the Trias.

Fossils.

Upper Coal-measures.—Fish of the genera, *Ctenoptychius*, *Megalichthys*, *Diplopteris*, *Palæoniscus*, *Platysomus*, *Diplodus*, and large bony rays resembling those of Burdie House in Scotland.* Crustacea: *Cythere* (Cypris) *inflata*. Annelides: *Spirorbis carbonarius*. Plants of the usual Coal-measure species.

Middle Coal-measures.—Fish: *Holoptychius*, *Platysomus*, *Palæoniscus*, *Cœlacanthus*, *Megalichthys*, *Diplopteris*, *Ctenoptychius*, *Diplodus*.† Molluscs: *Anthracosia* and *Modiola*. Plants: *Coniferæ*, *Lepidodendron*, *Sigillaria*, *Calamites*, *Halonia*, *Knorria*, &c., and ferns.‡

Lower Coal-measures.—Fish: several of those above-named. Molluscs: *Goniatites undulatus*, *Listeri sphericus*, *reticulatus*, *mutabilis*, *calyx*, &c.; *Orthoceras attenuatus*, *sulcatus*; *Nautilus carinatus*; *Bellerophon*, *Aviculopecten papyraceus*, *Pecten dissimilis*, *Posydonia*, *Lingula*, *Modiola minuta*, *Spirifer Gloveri*, *filaria*; and *Productus* (doubtful specimens), lying above one of the lower coals at Burnley.

Resources of the Lancashire Coal-field.

In estimating the resources, it will be necessary, as

* Binney. Trans. Geol. Soc. Manchester, vol. i.

† *Ibid.* "On the Fishes of the Pendleton Coal-field."

‡ Of these there are specimens in the Museum of the Geol. Society of Manchester.

already stated, to discard from our calculations the Lower Coal-series with its thin Coal-seams, as these, from their insufficient thickness, are never likely to warrant mining at greater depths than about 350 yards.

Secondly, it will be most convenient to limit the inquiry to the actual coal-field included between the *Arley mine* and the highest Carboniferous strata of Pendleton (which lie about 330 yards above the *Worsley four-feet coal*), including in all 4000 feet of strata. All these beds dip under the newer formations towards the valley of the Mersey; and their depth may be calculated from the thickness of these formations, as given at the head of this chapter. (Page 122.)

1. Area of the coal-field (exclusive of the Manchester and Burnley fields) ..	192 square miles.
2. Total thickness of strata down to the Arley mine	4,000 feet.
3. Number of workable coals above 2 feet; St. Helens, 13; Wigan, 16; Pendleton, 18; giving an average thickness of	60 feet of coal.
4. Total original quantity of coal (corrected for denudation)	5,947 millions of tons.
5. Deduct for quantity already raised, 1-6th ..	4,956 " "
6. Deduct for waste, &c., 1-4th; leaving for future use	3,700 " "

Note.—For the calculation of the probable duration of this coal-field see p. 135.

THE MANCHESTER COAL-FIELD.

The north-eastern side and suburbs of Manchester stand upon a small coal-field, entirely enclosed by New Red Sandstone, except at Collyhurst, where it is in contact with Permian strata. The shape of this coal-field is oblong, with its longest diameter lying N.N.W., and about four and a half miles in length; in its broadest part it is about a mile and a half across.

South of the fault which crosses it north of Miles Platting, and throws in on the north side the Permian beds of Collyhurst, the dip of the strata is south-west. The highest beds consist of red clays, shales, sandstones, and six beds of limestone, containing *Spirorbis* and fish; two thin coal-seams, and a bed of black-band ironstone containing in great abundance *Anthracosia Phillipsii*, and scales of fish. Mr. Binney considers this to be identical in position with the black-band ironstone of the Upper Coal-measures of Stoke, Staffordshire. These strata can be traced along the banks of the river Medlock, at Ardwick. The fossils which they contain have already been described. Beyond question this is the finest representative series of Upper Coal-measures in the whole of Britain. Below these calcareous beds, there occurs a thick series of shales, sandstones, &c., with seven beds of coal, the thickest of which is only four feet. One of these coal-seams is probably on a parallel with the Worsley "four-feet" mine and its associated strata; but the thick coals, which lie about 1000 feet below this coal at Pendleton, have not yet been reached in the Manchester coal-field.

Iron Ore.—Mr. Binney, who has described this district with a fulness that leaves little to be required, has discovered in the bed of the Medlock a calcareous hæmatite, occurring in large blocks, which he considers identical with the valuable ore now being worked at Patricroft.*

THE BURNLEY COAL-FIELD.†

Situated some ten miles to the north of the main mass of the Lancashire coal-field, and connected by a mountainous tract of Lower Coal-measures and Millstone Grit, the small, but rich coal-basin of Burnley occupies a valley encircled by hills of these formations.

The outline of this coal-field is nearly oval: its longest axis, lying north-east and south-west, traverses Burnley. It is about seven miles in length and five in greatest breadth.

The eastern side of the coal-basin is bounded by a large fault, along which the Lower Coal-measures have been upheaved on the east side into high, terraced hills, while on the west side of the fault the productive Coal-measures plunge at high angles towards the centre of the basin. In this direction they gradually flatten; and at Burnley are perfectly horizontal. On approaching the opposite side of the basin, the dip rapidly augments; and along the base of Padiham Heights the strata rise to the surface in rapid succession.

There is one point of much interest in connection with this coal-field. A transverse section across the

* "On the Geology of Manchester."—Trans. Geol. Soc. Manchester, vol. i.

† My information regarding this coal-basin is derived from my friend Mr. Binney, and from a visit in company with members of the Geological Society of Manchester, at the invitation of Sir J. Kay-Shuttleworth of Gawthorpe Hall. I have also to acknowledge some notes furnished by Mr. T. T. Wilkinson of Burnley.

ridges of Padiham Heights and Pendle Hill, in the direction of Clitheroe, gives in unbroken succession a complete series of beds from the *Fulledge main coal*, or Arley mine, to the Carboniferous Limestone; and I believe it is the only spot in Lancashire where none of the links of this chain of rocks are absent.

This section includes:—1. The outcrop of the "Arley mine," under Padiham reservoir: 2. The Lower Coal-measures, or Gannister beds, with thin coal-seams; 3. The "Rough Rock" and the beds of Millstone Grit, the lowest of which forms the escarpment of Pendle Hill, 1831 feet in height; and 4. The Limestone Shale or Yoredale series passing downwards into massive encrinital limestone. The whole of this series reaches a thickness probably little short of 10,000 feet.

Succession of Coal-seams at Burnley.

	Thickness. Feet.
Strata	30
1. *Doghole Coal*	6
Strata	21
2. *Kershaw Coal*	3
Strata	81
3. *Shell Coal* (Anthracosia)	2½
Strata	18
4. *Main Coal*	5
Strata	33
5. *Maiden Coal*	3
Strata, with 8 thin coal-seams (*Anthracosia robusta*)	162
6. *Lower Yard*, or *Five-feet Coal* (with shales) ..	5
Strata	21
7. *Lower Bottom Coal* or *Four-feet Coal* ..	3½
Strata	78
8. Impure Cannel	2¼
Strata	21

			Thickness. Feet.
9.	*Thin Coal* and "fish bed"*		$2\frac{3}{4}$
	Strata		66
10.	*Great Mine*	Coal 28 inches; Shale 12 „; Coal 19 „ ..	4 (coal)
	Strata		201
11.	*China Bed*		2
	Strata, ...		99
12.	*Dandy Bed*		2
	Strata		141
13.	*Fulledge main coal* or *Arley mine*		4

Lower Coal-measures, with Gannister coal, and two or three other seams with roofs containing Goniatites, Aviculo-pecten, &c.
Millstone Grit series, with several thin coals.

From this section it will be seen that, near the centre of the basin, there are 1017 feet of strata, down to the lowest thick coal, representing the *Arley mine* of Wigan, or the *Dogshaw mine* of Bury. There are about twelve workable coal-seams, with 40 feet of coal; and about 200 yards above the Fulledge main seam we find the bed of *Anthracosia robusta*, apparently the same species which occurs in the Wigan district, 47 yards above the Arley mine.

Resources.

The basin-shaped structure of this coal-field has only recently been determined; and consequently, towards the centre, the lowest coals lie still undisturbed by the miner's pick, these seams having till recently been worked only near their outcrop. The upper seams occupy a comparatively small area; and without pretending to accuracy, we may assume the quantity already worked out at one-tenth of the whole.

* For species collected by Mr. G. Wild, see Trans. Geol. Soc. Manchester, vol. ii., p. 6.

The coals of the Gannister series are not included in the following estimates:—

1. Area	20 square miles.
2. Thickness of strata 1,017 feet, with 40 feet of workable coal.	
3. Total original quantity (corrected for denudation)	403 millions of tons.
4. Deduct for quantity worked out 1-10th.	
5. Deduct for waste, &c., 1-4th.	
6. Leaving for future use about 270 millions of tons.	

The thin coal-seams of the Lower Coal-measures are worked at Church, Quarlton, and Darwen, and are spread at intervals over a large extent of the hilly districts beyond the boundaries of the middle or productive series.

General Summary of Resources of the Lancashire Coal-fields.

1. Area of the main coal-field	192	square miles.
2. " Manchester coal-field ..	5	"
3. " Burnley coal-field ..	20	"
Total	217	"

Quantity of available Coal.

1. Main coal-field	3,700	millions of tons.
2. Manchester coal-field	20	" "
3. Burnley coal-field	270	" "
Total	3,990	" "

The quantity of coal raised in 1859 was 10,650,000 tons. Taking the future production at 11 millions of tons, there is sufficient coal to last for 363 years (note, p. 136).

The above calculation includes the coal within a vertical depth of 4000 feet.

This coal-field in 1859 contained 416 collieries—viz.: Lancashire, 381; Cheshire, 35,—the latter producing 700,500 tons. The number of collieries in 1857 was only 390.

Note.—Mr. Hunt in the Introduction to the "Mineral Statistics," for 1859, states that Her Majesty's Inspectors estimate the quantity of coal raised in that year at even a higher figure than that stated above, amounting to no less than 11¼ millions of tons. Mr. Hunt considers this as slightly an over-estimate—but we may fairly assume 11 millions as an average result. The increase within the last few years has been very great, as the amount raised in 1857 was only 8,565,500 tons.

CHAPTER XIV.

CUMBERLAND COAL-FIELD.

THE zone of Carboniferous rocks which wraps round the northern flanks of the Cumberland mountains is surmounted by the rich coal-field of Whitehaven, Workington, and Maryport. Between this last town on the north and St. Bees' Head on the south, it stretches along the coast of the Irish Sea, and extends inwards for a distance of five miles, in which direction the beds rise and crop out. From Maryport the coal-field extends eastward to Bolton. Its total length is about 20 miles, and greatest width, at Workington, about 5 miles.*

From the Memoir of Professor Sedgwick, who has recorded the distinctive features of this coal-field, I gather the following descending series.†

* Ruthven's Geological Map of the English Lakes.

† Trans. Geol. Soc. of London, vol. iv. I have also been kindly assisted by Mr. Dickson, of Whitehaven, who has furnished several colliery sections and much general information.

Succession of Strata.

New Red Sandstone of St. Bees' Head, decomposing into grotesque and castellated forms.

Permian strata .. 1. Gypseous marls surmounted by sandy marls and micaceous sandstone.

2. Conglomerate of magnesian limestone, &c., resting on an eroded surface of the Whitehaven sandstone.

3. (?) Massive reddish sandstone of Whitehaven. Professor Sedgwick appears doubtful of the affinities of this rock—100 to 150 feet.

Coal-measures 2,000 feet * .. 1. *Upper*, most fully developed at Cleat Moor, containing 7 workable coal-seams.

2. *The Lower*, with 4 or 5 thin and inferior coal-seams.

1. Grits and limestone shales, with thin bands of coal at Hesket New Market.

Succession of the Coal-Seams.

Whitehaven.

		Thickness. Feet.
	Strata	432
1.	*Yard Band* (about)	3
	Strata	30
2.	*Coal*	2½
	Strata, with a thin coal-seam	78
3.	*Bannock Band*	8 to 9
	Strata	60
4.	*Main Band*	6 to 11
	Strata	240
5.	*Low Bottom Coal*	4

Workington.

	Strata	132
1.	*Fiery Band*	2
	Strata	96

* Mr. Dickson calculates this at considerably less.

	Thickness. Feet.
2. *Brassy Band*	$2\frac{1}{4}$
Strata	72
3. *Cannel* or *Metal Band*	4 to 6
Strata	60
4. *Bannock Band*	$5\frac{1}{2}$
Strata	30
5. *Little Main Band*	3 to 4
Strata	180
6. *Main Band*	9 to 10
Strata	210
7. *Yard Coal*	2 to 3
Strata	102
8. *Four-feet Coal*	4
Strata	150
9. *Udale Band*	3 to 4

At Maryport, beneath the Lower Red Sandstone, there occurs the "Ten-quarter coal," 7 feet thick, supposed to represent the "Bannock Band" of Workington, and the "Metal" and "Cannel bands," separated by 36 feet of strata, are considered to represent the "Main band."

The thick coals of Workington are thrown out south of that town by a large fault, upheaving the Lower Coal-measures, which occupy an extensive plateau, stretching from Harrington to the hills north of Moresby. Another great fault, with a downthrow on the south-west, again brings in the productive measures of Whitehaven. Unfortunately, however, between this fault and the village of Parton, the beds dip to the east, so that all the coal-seams below high-water mark crop out under the sea, and the coal cannot be extracted on account of the quantity of sea-water which finds its way along the planes of bedding. In some positions the coal has been followed more than a mile under the sea.

From Workington to Flimby, a large unwrought coal-field is supposed to exist, and from Workington to Maryport the general dip of the strata is north-west, and the coals crop out inland, where they have been worked to some extent in very early times.

From Maryport to Bolton, by Crosby and Aspatria, the coal-seams are overlaid by the newer strata of either Permian or Triassic age.

Resources.—Probably not more than one-fourth of the thick coal of this field remains to be extracted. Much of it has been destroyed by denudation. A smaller portion has already been exhausted, and a still smaller cannot be won on account of physical obstructions. We may thus sum up its capabilities for future supply:—

1. Area of middle productive measures ..	25 square miles.
2. Average thickness of workable coal	15 feet.
3. Quantity of coal originally	387 millions of tons.
4. " " worked out and destroyed .	290 " "
5. " " remaining for use	97 " "

Which would last for nearly 100 years at the present rate of production.

In 1859 there were 28 collieries, raising 1,041,890 tons of coal.

CHAPTER XV.

WARWICKSHIRE COAL-FIELD.*

THIS is a small but rich coal-field, extending towards the south-south-east from a mile east of Tamworth, in a constantly narrowing band, by Atherston and Nuneaton, to near Wyken—a distance of 15 miles. At the northern end the strata form a trough four miles in breadth, bounded on the west, north, and east by large faults which bring in the New Red Sandstone. The Coal-measures dip under a large district occupied by Lower Permian rocks, extending under Coventry and Warwick. This tract, with an area of 90 square miles, is underlaid by coal at a depth not greater than 2500 feet in any part, often much less. At the south end of the coal-field the whole of the Coal-measures are overlapped by the New Red Sandstone, which passes across the edges of the beds and rests upon the Permian rocks. The prolongation of the coal-seams under the Trias has been proved for more than two miles.

* For details of this coal-field see Mr. Howell's Memoir "On the Geology of the Warwickshire Coal-field, &c.," and the Maps and Sections of the Geological Survey. The section of the coal-field is reduced from No. 5, Sheet 51, by Mr. Howell.

General Succession of the Formations.

		Maxim. thickness. Ft.
Trias ..	1. Red Marl	600
	2. Lower Keuper Sandstone	180
	3. Bunter Sandstone, only sparingly represented.	
Lower Permian Rocks.	1. Brown and purple sandstones and marl with calcareous breccia and conglomerate with *Strophalosia?* *Labyrinthodon*, and plants	2,000
Coal-measures.	1. Sandstones and shales, at the base of which, a band of limestone with *Spirorbis carbonarus*	50
	2. Coal-measures with five workable coals lying near the centre of the series	1,400
	3. Lower Coal-measures unproductive of coal, and traversed by dykes of greenstone	1,500
Millstone Grit.	1. Hard siliceous rock, with bands of shale, altered by intrusive greenstone (about) ..	500

Coal-seams.—The five workable coals lie about 1000 feet below the *Spirorbis* limestone. At the northern end of the district they are separated by about 120 feet of shales and sandstones, which all decrease in thickness, while the coals remain nearly the same, and at Wyken,

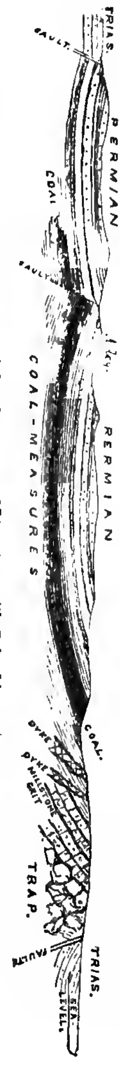


Fig. 13.—SECTION ACROSS THE CENTRE OF THE WARWICKSHIRE COAL-FIELD.
Length about 6 miles.

near Coventry, the five seams combine to form one bed of coal 26 feet in thickness. This is a change parallel to that which occurs in South Staffordshire in the case of the *thick coal,* which becomes split up northwards from Wolverhampton. Both cases exemplify in a remarkable degree the greater persistency of coal-beds over the sedimentary strata with which they are associated.

Resources.

1. Area ot coal-field (beyond the boundary of the Permian rocks to the outcrop of the "Seven-feet coal")	30 square miles.
2. Thickness of coal	26 feet.
3. Original quantity of coal (corrected for denudation)	627 millions of tons.
4. Deduct for quantity worked out, and loss 1-3rd ; leaving for future use	418 " "

Which at the present rate of consumption, 355,750 tons, would last for about 1,000 years.

Under the Permian rocks there is about an equal quantity of coal at a depth of less than 2500 feet, and about four times as much under 4000 feet. Mr. Howell's sections show the probability that the coal-seams lie very regularly, and nearly horizontally under this formation. I cannot, therefore, but regard as of peculiar value this vast reservoir of fuel lying at the borders of the south-eastern counties, and actually closer than any other coal-bearing district to the metropolis of Britain.

The Lower Coal-measures are traversed by several intrusive dykes of greenstone, which *nearly* correspond with the planes of bedding. These dykes have been injected subsequently to the deposition of the Coal-measures, as they have baked and blanched the shales with which they are in contact. At the base of these strata we find the Millstone Grit changed into quartz rock through the influence of a mass of greenstone upon which it rests. Beyond this the whole of the strata are broken off by a great fault, which introduces the Trias.

CHAPTER XVI.

THE LEICESTERSHIRE COAL-FIELD.*

THIS small but valuable coal-field occupies an irregularly-shaped district south of the Valley of the Trent. Along its western, northern, and southern sides, it is bounded by strata of the age of the Trias; and along the north-east, by the ancient slates, and porphyries of Charnwood Forest, which form a miniature mountain range, rising in rugged knolls, and serried ridges above the general level of the country. The Coal-measures underlie the New Red Sandstone to a large and unknown distance towards the south and west; and in the

* This coal-field has been very ably illustrated by Mr. Mammatt, in his "Geological Facts," and more recently by the works of the Geological Survey, consisting of Maps 63, N.W., 71, S.W.; Horizontal and Vertical Sections; and a Memoir "On the Geology of the Leicestershire Coal-field," by the Author, 1860. The Rev. W. H. Coleman has also largely contributed to the knowledge of a district of peculiar geological interest.

WEST. EAST.

Fig. 14.—SECTION ACROSS THE LEICESTERSHIRE COAL-FIELD.
Distance about 12 miles.

4. Keuper Beds.
3. Bunter Conglomerate.
2. Middle Coal-measures, with coal.
1. Lower Coal-measures.
P. Porphyry } Cambrian Rocks of
S. Slate, } Charnwood Forest.
× Faults.

Coleorton district several collieries are situated upon the Keuper Red Marl, and pierce this formation downwards to the coal beneath; the deepest of these shafts is at Bagworth colliery.

The coal-field is physically divisible into three districts—that of Moira, on the west; Ashby-de-la-Zouch, in the centre; and Coleorton, on the east. The central district is formed of Lower Coal-measures, without workable coals, and is bounded on both sides by down-cast faults, which introduce the workable coal-beds of Moira and Coleorton. The coal-series of these latter districts cannot be identified with each other, though they are probably synchronous. "The main-coal" of Moira is from twelve to fourteen feet thick; that of Coleorton, from six to eight feet.

General Succession of Formations—Leicestershire.

Trias ..	Keuper series	700 ft.
	Bunter, (sometimes absent)	200 "

Permian Rocks	Breccia, sparingly represented.	
Carboniferous Series.	1. Middle Coal-measures, with about 20 coal-seams, of which 10 are workable	1,500 ft.
	2. Lower Coal-measures, unproductive ..	1,000 „
	3. Millstone Grit	50 „
	4. Yoredale series and Carboniferous Limestone.	

The following is a list of the coal-seams in both the Moira and Coleorton districts.

Coal-seams of the Leicestershire Coal-field.

Moira District—(West.)	Ft.	In.	Coleorton District—(East.)	Ft.	In.
Ell Coal (*b*)	3	8	Stone smut (*c*)	4	9
Dicky Gobbler (*b*) ..	3	6	Swannington (*a*)	3	7
Block Coal (*a*)	3	6	Slate-coal (*b*)	4	8
Little or Four-feet (*a*) ..	4	6	Coal	2	10
Cannel (*b*)	3	6	Coal -	3	7
Main { Over seam / Nether seam } ..	12	0	Main-coal (*a*)	6	0
			Upper Lount (*b*)	3	9
Toad (*c*)	3	6	Second Lount (*b*) ..	3	0
Little Woodfield (*c*) ..	2	6	Middle Lount	4	6
Woodfield (*b*)	5	0	Nether Lount	4	6
Stockings (*c*)	9	0	Heath End Coal & Cannel	10	0
Eureka (*a*)	4	6	Lower Coal-measures.		
Strata below this unproved.					

In the above list, I have omitted several of the least important coals. The letters *a*, *b*, *c*, indicate the degrees of quality.

I shall conclude this account of the Leicestershire coal-field by stating a few geological facts of interest.

Igneous Rocks.—At Whitwick, a remarkable *bed* of "whinstone" or greenstone, intervenes between the Coal-measures and the New Red Sandstone. In one of the shafts of Whitwick colliery it is 60 feet thick, and has turned to cinders a seam of coal with which it comes in contact. It has evidently been poured out as a sheet of lava over the denuded surface of the Coal-measures at some period prior to that of the Trias.

Rock-faults.—In the same district, the main-coal has been extensively invaded by channels filled up with fine sand, which completely replace the coal over several hundred yards. One of these banks of sandstone, at Pegs-green colliery, was found to be 80 yards in width. It is composed of the same sandstone that forms the roof of the coal itself. In another of these, south of Whitwick colliery, a tunnel was driven to a distance of 110 yards without passing through it. These phenomena are similar to those already described in the case of the coal-field of the Forest of Dean.

Salt-water.—In the Main coal of Moira, especially in the Bath colliery, at a depth of 593 feet, salt-water, beautifully clear and of nearly the same composition as sea-water, trickles down from the fissures where the coal is being extracted. The brine is carried to Ashby de la Zouch in tanks, and is considered highly beneficial in scorbutic and rheumatic affections.

Resources.

1. Area of productive coal-field	15 square miles.
2. Number of workable coals above 2 feet ..	10, with 13 yards of coal.
3. Total original quantity of coal	302 millions of tons.
4. Deduct for quantity raised one-half, spoiled one-third, leaving for future use ..	50½ „ „
6. But the quantity under the New Red Sandstone at a depth under 3000 feet is at least double the above supply, making a total of	150 „ „

Which at the present rate of production, 800,000 tons, would last about 200 years.

In the Leicestershire coal-field there are 14 collieries, five of which work the coal under the New Red Sandstone. There are at present no iron-furnaces.

Fossils.—The plant remains are abundant, and have been figured in Mammat's "Geological Facts." The only shells are of the genus *Anthracosia;* and of crustacea—*Cythere,* or *Cypris,* of an undescribed species, discovered by Mr. H. Green.

CHAPTER XVII.

DERBYSHIRE AND YORKSHIRE COAL-FIELD.

THIS great field, though forming parts of the shires of Derby, Nottingham, and York, is physically *one;* and in treating of its structure and resources we must ignore political and social landmarks. It is the largest coal-field in England; and about 150 square miles smaller in area than that of South Wales.

Its eastern boundary is the escarpment of the Magnesian Limestone, with its subordinate Lower Permian strata, which, commencing near Nottingham, extends northwards beyond the limits of the coal-field itself. Upon reaching the crest of the escarpment, you find yourself on the edge of a table-land, resembling that of the Oolite of Gloucestershire, but less lofty. One point of this ridge is crowned by the turrets of Bolsover Castle. The southern boundary is New Red Sandstone, and the strata rise and crop out westward as far north

Fig. 15.—GENERAL SECTION ACROSS THE DERBYSHIRE AND YORKSHIRE COAL-FIELD. Drawn along the border of the two counties into Notts. Distance 25 miles.

1. Trias. 2. Magnesian Limestone, &c. 3. Coal Measures, with coal. 4. Millstone Grit. 5. Yoredale Rocks. 6. Carboniferous Limestone.

as Bradford and Leeds, where they bend round to the east, and finally disappear under the Magnesian Limestone, which passes over and rests directly on the Millstone Grit. The greatest length of the coal-field from south to north is 66 miles; and its breadth varies from five to twenty miles. Though the general dip of the strata is eastward, there generally occurs along the centre of the field a gentle undulation (shown in the section, fig. 15), which for a certain distance produces a westerly dip; but the strata always roll over when approaching the base of the Permian Rocks. The coal-seams are only occasionally broken by faults.

To the westward, the Lower Carboniferous series rise into the lofty ranges of the Pennine chain, forming a natural division between the counties of Stafford and Lancashire on the west, and Nottingham and Yorkshire on the east, as well as their respective coal-fields. In fact, the upheaval of the Lower Carboniferous rocks, has rent asunder a coal-field which originally stretched across from Staffordshire and Cheshire to Nottinghamshire and Yorkshire.

The loftiest escarpment of this central chain is Mickle Fell, formed of Millstone Grit, 2600 feet; and the Carboniferous Limestone of Derbyshire reaches an elevation of 2533 feet.*

Succession of Strata.

Southern Extremity—Derbyshire and Notts. The succession of strata along a line drawn from Kirkby Woodhouse through Alfreton Common and Wingfield Manor to Crich, may be very clearly ascertained, both from the details of the collieries, and the natural sections which present themselves. The following is the series in descending order.

		Feet.
Permian Rocks.	1. Marls and sandstone	40
	2. Magnesian limestone (lower bed) ..	60
	3. Marls and sandstone	30
Middle Coal-measures 2,500 ft.	Strata to Top Hard Coal, about ..	700
	Waterloo Coal	1,600 (Waterloo Coal to Shales with iron-stones)
	Ell	
	Lower Hard	
	Furnace	
	Black Shale or Clod	
	Kilburn	
	Shales with iron-stones	
Lower Coal-measures, or Gannister series.	Flagstones of Wingfield Manor.	
	Shales and flaggy sandstones, with two coals underlaid by Gannister floors	1,000

* See Professor Phillips' "Geology of Yorkshire," where the physical features of the Pennine chain are graphically portrayed; also Mr. Denny's "Fossils of the Yorkshire Coal-field," Proc. Geological Society, Yorkshire, vol. ii.

			Feet.
Millstone Grit	Rough rock. Flags and shales. Hard millstone	.. ..	350
Limestone Shale, or Yoredale Rocks		.. ..	250

The Black Shale coal represents the "Arley mine" of Lancashire; and the Kilburn coal, the "Low Moor coal" of Yorkshire. In the lower beds there are several valuable ironstones, filled with *Anthracosia.* The whole series is very thin when compared with their representatives in Lancashire.*

For the purpose of affording a comparison of the formations towards the north and south of the field, I select sections from Nottinghamshire, and Barnsley in Yorkshire.

General Section of Strata.

Nottinghamshire.†—(Shireoak Colliery.)		Ft.	Barnsley, Yorkshire.‡	Ft.
Permian Rocks.	Upper Permian marls and sandstone	56	Magnesian Limestone ..	75
	Magnesian limestone	102	Lower Permian Sandstone .	54
	Lower Permian sands and shale	38		
Strata, with beds of hæmatite and ironstone ..		42	*Ackworth rock*	54
The Manor Coal		2	Strata	510
			Shafton Coal	5

* Horizontal Section of the Geol. Survey, Sheet 60. The author is much indebted to Mr. Bean, manager of the Butterly Company's Works, for assistance and information.

† Partly taken from section of Shireoak Colliery by Messrs. Lancaster and Wright. Journ. Geol. Soc., vol. xvi., p. 138.

‡ Rev. W. Thorpe, Section of Strata.—*bid.*

General Section of Strata—continued.

Nottinghamshire.	Ft.
Strata, with several thin coals	706
Shireoak or *Melton*, or *Baelbro' Hall Coal*	4¼
Strata, with an inferior coal, 3/2 thick	120
Furnace Coal	2¾
Strata	138
Hazles Coal	3
Strata	238
Top Hard Coal (or *Barnsley Coal*)	3¾
Strata .. / *Dunshill Coal*, 2¾ / Strata .. }	155
Waterloo Coal	½
Strata, with 2 coals, two feet each in thickness	345
Soft Coal	3½
Strata	120
Lower Hard Coal	4
Strata / *Piper Coal*, 2¼ / Strata }	200
Furnace Coal	4
Strata	360
Clod or *Black Shale Coal* ..	6
Strata	480
Kilburn Coal	5
Strata (with ironstone) ..	350
Furnace[1] *Coal*	2½
Strata (principally shales)	150?
Lower Coal-measures.–Flagstones, shales, and the coals with Gannister, thickness rather uncertain (about) ..	500
Millstone Grit.	

Barnsley, Yorkshire.	Ft.
Strata, principally sandstone (Chevit rock)	393
Muck Coal	3½
Strata	219
Woodmoor Coal	3
Strata with half-yard coal ..	45
Winter Coal	4
Strata	
Beamshaw Coal	3
Strata, with Kent Coal 1 foot, and Mapple Coal 4½ feet (inferior quality)	
Strata	216
Barnsley Coal	9¼
Strata	198
Swallow Wood Coal ..	3
Strata	234
Joan Coal	2
Strata	60
Flocton Top Coal	3¼
Strata	120
Park Gate Coal	5
Strata	78
Thorncliffe thin Coal ..	2½
Strata	123
Four-feet Coal (variable) ..	2½
Strata	108
Silkstone Coal	5
Strata	195
Whinmoor or *Lowmoor Coal*	2½
Strata .. .. (about) ..	150
Gannister flagstone (about) ..	36
Strata, principally shales ..	495
Halifax Coal, (with *Pecten papyraceus* in the roof), and a floor of Gannister ..	1¾
Strata (shales and flags) ..	81
Halifax soft Coal	1½
Strata	150
Millstone Grit.	

In Derbyshire the principal coals are the "Top hard" and "Lower hard" seams, producing the valuable splint-coal, and in Yorkshire the most remarkable are the "Silkstone" and "Barnsley thick coals." The former is undoubtedly identical with the "Arley mine" of Lancashire; and thus this fine bed of coal, which seldom exceeds five feet in thickness, has originally spread over a tract embracing not less than 10,000 square miles!

In the Lower Coal-measures, or Gannister beds, described originally by Professor Phillips,* one or more of the coals, with their roofs of black shale filled with *Aviculo-pecten papyraceus*, *Goniatites*, *Posidonia*, &c., can be identified with those which range over North Lancashire: all of which facts go to prove the original continuity of these great coal-fields.†

Fossil Remains.—These have been summed up by Mr. Denny‡ as consisting of 17 species of fish (placoid and ganoid). Of molluscs, 5 cephalopods, 17 conchifers and brachiopods. Crustacea, *Cythere* (Cypris). In the roofing shale of several of the coal-beds fish remains occur, and so plentifully in the case of one of these, at Middleton, that the miners call it the "fish-coal." In the roof of the "Halifax coal," of the Lower Coal-measures, *Goniatites Listeri* is found throughout its entire course, sometimes beautifully preserved in iron pyrites, and with this is associated *Aviculo-pecten papyraceus.*

* Article "Geology," in *Encyclopedia Metropolitana.*
† See Mr. Binney, Trans. Geol. Soc. Manchester, vol. ii., part 7.
‡ Proc. Geol. Soc. Yorkshire, vol. ii.

In the "Catherine Slack coal" near Halifax, *Nautilus Rawsoni* and *Orthoceras Steinhaueri* are frequent.

In the Middle Coal-measures there are bands of ironstone, filled, over a great extent of country, with *Anthracosia* (Unio) and *Cythere* (Cypris).

The Coal-measures under the Permian and Trias.—I have already stated that the whole of the coal-field dips at a very small angle beneath the escarpment of the Magnesian Limestone; and there is probably as large an amount of coal below this formation as beyond its westerly limits. The greatest thickness of the Permian beds is shown in the section of Shireoak colliery to be 200 feet, as the shaft commences at the base of the New Red Sandstone;* and as the depth increases very gradually eastward, the "Shireoak" and "Top hard" coals must occupy a very large extent of ground at a less depth than 1000 yards, though the diminished thickness of the latter at Shireoak shows a general tendency to thin away towards the east. In Yorkshire there does not appear to be any tendency to an easterly thinning out of the coal-seams; but they usually *rise* towards the north-east, near to and under the Magnesian Limestone.†

Iron Ores.—There are several courses of valuable ironstone in this coal-field, supplying about 50 blast furnaces, yielding in the West Riding 96,200 tons of pig-iron, and in Derbyshire 106,960 tons. In addition to these the Cleveland ores, which are derived chiefly from

* As I am informed by my colleagne, Mr. W. T. Aveline.

† As I am informed by Mr. Charles Morton, H. M. Inspector, to whom I am indebted for information regarding this coal-field.

the Middle Lias, yielded in 1857 upwards of one million of tons.

Resources.

In estimating the resources of this coal-field I include only the workable seams of the Middle Coal-measures; the coals of the Gannister series, though frequently of good quality, being too thin to be worked at depths much greater than 300 yards.

1. Area of coal-field (not including that portion underneath the Magnesian Limestone)	760 square miles.
2. Greatest thickness of productive coal-measures (from the Ackworth rock above the Shafton coal to the Low Moor coal)...	2,500 feet.
3. Average number of workable coals above 2 feet, 15; giving a vertical thickness of coal	46 „
4. Total original quantity of coal (corrected for denudation)	17,656 millions of tons,
5. Deducting 1-4th for the quantity worked out, and 1-4th for waste, &c., we obtain for future use (about)	8,800 „ „
6. The area, overspread by Permian (Magnesian Limestone) and Trias, under which several of the workable coals lie at a depth within 4,000 feet, is about 400 square miles, containing	12,000 „ „
7. From this deduct 1-3rd for loss, leaving for future supply	8,000 „ „
8. Total available quantity under 4,000 feet in depth is therefore 8,800 + 8,000 ..	16,800 „ „
9. This at the present rate of consumption would last for 1,340 years.	

This result shows to how limited an extent the great resources of this coal-field are as yet developed. In fact we may in some parts traverse large districts well stored with coal, where not one colliery is in sight, and the fact becomes more apparent when we recollect that the great tract occupied by Magnesian Limestone and New Red Sandstone—under which the whole of the beds of coal are known to descend—is as yet pierced only by five collieries, producing, as I am informed by Mr. Morton, about 200,000 tons of coal annually.

The produce of this coal-field has been nearly stationary for the last three years, owing probably to the depression in the iron-trade during 1859. There were, in 1859, 559 collieries, producing 12,497,100 tons of coal, which may be thus arranged:—

Derbyshire and Notts ..	176 collieries ..	4,250,000	tons of coal.
Yorkshire	383 „ ..	8,247,100	„ „
Total	559 ..	12,497,100	„ „

CHAPTER XVIII.

GREAT NORTHERN COAL-FIELD OF DURHAM AND NORTHUMBERLAND.

The general succession of the strata and their relative position over the area of this coal-field is similar to that of Yorkshire, so that one section will serve to illustrate the structure of both. I must therefore beg the reader to refer to the transverse section at the commencement of the last chapter (fig. 15, p. 148).

The Great Northern coal-field extends from Staindrop, near the north bank of the Tees, on the south, to the mouth of the Coquet, where it enters Alnmouth Bay, on the north, the distance being nearly 50 miles. Its greatest diameter is near the centre, along the course of the Tyne, which forms the great highway for the export of coal to the London market.*

From the Coquet to the Tyne the North Sea forms the limits of the coal-field. South of this the escarpment of the Lower Permian Sandstone and Magnesian Limestone forms the boundary at the surface; but the Coal-measures underlie these newer rocks, and since Dr. William Smith,† first on theoretical grounds and afterwards by actual experiment, demonstrated the existence of the coal-field at Haswell near Durham, both the Triassic and Permian formations have been perforated over a large area, especially at Seaham and Ryhope in Durham. The general dip of the strata is easterly as far as the margin of the sea, where they are almost horizontal.‡ The Permian strata are unconformable to the Coal-measures; and from the mouth of the Tyne southwards they rest successively on lower beds, till, at the south end of the coal-field, they finally overlap the whole coal-series, and for a distance of 48 miles (from the bank of the Tees to the margin of the Yorkshire coal-field) repose directly upon Millstone Grit and Yoredale Rocks.

* I have calculated the area of this coal-field from Mr. W. Oliver's map in the *Mining Record* office. There are some interesting details in "Our Coal and our Coal-pits," published by Messrs. Longman.

† About half a century ago.

‡ As I am informed by Mr. M. Dunn, H. M. Inspector, to whom I am indebted for much information.

From below the coal-field of Durham and Northumberland the Lower Carboniferous Rocks rise towards the west and north into swelling moorlands, and ultimately into the mountainous tract of the Pennine chain, attaining, at Hedge Thorpe a height of 2347 feet, and at Yevering Bell, 2000 feet.

*General Series of Formations.**

New Red Sandstone.—*Red sandstone* and conglomerate.

Permian Rocks. Magnesian Limestone) 500 to 600 feet.	1. Upper Permian marls, with gypsum	100 feet.
	2. Crystalline limestone, with *Schizodus Schlotheimi*, and *Mytilus septifer*.	
	3. Brecciated limestone (Tynemouth Cliff), lying on—	
	4. Fossiliferous limestone, with *Productus*, *Strophalosia*, *Athyris*, *Avicula*, &c., and numerous bryozoa.	
	5. Compact limestone, with similar fossils.	
	6. Marl slate, calcareous shales and thin-bedded limestone, with fishes of the genera *Palæoniscus*, *Acrolepis*, *Platysomus*.	
	7. Lower Permian sandstone with gypseous marl, *Pinnites Brandlingi*, *Trigonocarpum*, *Sigillaria reniformis*, *Calamites approximatus*	200 ,,
Coal-Measures. 2,030 feet.	1. Upper series, with thin coals, and a band of ironstone with *Anthracosia*, *Lingula Credneri*, *Cypris* or *Cythere inflata*, *Holoptychius Hibberti*	900 ,,
	2. Middle series. From the "High Main Coal" to the "Low Main Coal"	430 ,,
	3. Lower Coal-measures, with 2 beds of coal, between 2 and 3 feet thick	700 ,,

* From the works of Professor King and Professor Sedgwick.

Millstone Grit ——	Coarse grits and shales	414 ft.
Yoredale Rocks ——	Shale, with bands of limestone and thin coals	540 „
Scaur Limestone.* —	Ten beds of limestone, parted by as many beds of shale, containing coal-seams in Northumberland, upwards of	1,120 „

Note.—For a list of the fossils of the Permian and Upper Coal-measures, see Mr. J. W. Kirkby, Journ. Geol. Soc., vol. xvi., p. 412.

Coal-seams.†—The most important coal in the Newcastle district is the "High main" or "Wallsend" seam. It is the highest workable coal, and varies from 5 to 6 feet in thickness. It is traversed by the "90-fathom" dyke, and is persistent in its general character to its northern and western outcrop, but southward towards the valley of the Wear is split up into two seams by the intercalation of sandstone and shale.

"The "Bensham" seam, 20 fathoms below the "High Main," is very variable in its qualities, and is often unworkable. It acquires its chief value towards the east, and is worked extensively under the Magnesian Limestone at Sunderland. Its general thickness is 6 feet.

The "Low Main" seam is known to range from Widdington on the north to Ferry Hill on the south, a distance of about 40 miles. This coal, south and west of Newcastle, is moderately soft, and excellent for household use and coking. But passing northwards its character changes; it becomes very hard and less gaseous, and constitutes the most important bed of

* Professor Phillips' "Manual of Geology," p. 163.

† For the details of the coal-seams, I am indebted to Mr. Dunn, H.M. Inspector of Collieries.

steam-coal. Below these lie several other seams, which will become more extensively worked as the supply from the valuable beds above described becomes curtailed.

The following is a list of the general series of coal-seams, for which I am indebted to Mr. Dunn.

Coal Series of Northumberland and Durham.
(Newcastle District.)

		Ft.	In.
	Upper Coal-measures	900	0
1.	*High Main Coal*	6	0
	Strata	33	0
2.	*Metal Coal*	1	6
	Strata	33	0
3.	*Stone Coal*	1	6
	Strata	63	0
4.	*Yard Coal*	2	10
	Strata	63	0
5.	*Bensham Coal*	2	10
	Strata	78	0
6.	*Five-quarter Coal*	3	0
	Strata	48	0
7.	*Low Main Coal*	6	0
	Strata	60	0
8.	*Crow Coal*	2	10
	Strata	24	0
9.	*Five-quarter Coal*	3	8
	Strata	30	0
10.	*Ruler Coal*	1	10
	Strata	96	0
11.	*Townley* or *Harvey Coal*	3	1
	Strata	42	0
12.	*Jelly Coal*	2	2
	Strata	42	0
13.	*Stone Coal*	2	5
	Strata	18	0
14.	*Five-quarter Coal*	3	4
	Strata	30	0
15.	*Three-quarter Coal*	2	6
	Strata	54	0
16.	*Brockwell Coal*	2	11

The series below the Low Main coal are taken at Blaydon and Wylam, as they have never yet been worked at Newcastle.

Basaltic Dykes.—The coal-field is traversed by several basaltic dykes, generally ranging east and west, and running for several miles in nearly straight lines. The beds of coal on approaching these dykes become anthracitic, and ultimately worthless. Near Newcastle one of these dykes is also a fault, with a downthrow to the south of 90 fathoms: it coincides with the valley of the Tyne, and enters the sea north of Tynemouth. The Cock-field Fell Dyke, in South Durham, ranges from W. N. W. to E. S. E. There is also a natural system of fissures, called "cleats," ranging N. N. W.

Resources.

In estimating the extent of this coal-field, we must include not only the superficial area formed of the Coal-measures, but also the district overspread by the Magnesian Limestone and New Red Sandstone, as far south as the Valley of the Tees, there being no doubt whatever that most of the coal-beds are accessible under this area at a depth under 4000 feet. In the following estimates, I shall give the resources of each separately, as well as conjointly.

Actual Coal-field beyond the Magnesian Limestone.

1. Area	460 square miles.
2. Number of workable seams above two feet about 10, with thickness of	36 feet of coal.
3. Original quantity of coal (corrected for denudation)	8,548 millions of tons.

4. Deducting for quantity worked out, 1-4th, and waste, 1-4th, leaving	4,274 millions of tons
5. Deduct for quantity raised between 1856-9	48 " "
6. Leaving for future supply	4,226 " "

Quantity under the Permian and Trias.

1. Area, with coal under 4,000 feet in depth	225 square miles.
2. Thickness of workable coal	24 feet.
3. Quantity for future use, after deducting for loss, &c.	3,000 millions of tons.
4. Total quantity under 4,000 feet in depth is therefore 4,226 + 3,000 = ...	7,226 " "

5. This, at the rate of consumption for the year 1859, would last for about 450 years.

The produce of this Coal-field is slowly but steadily increasing, and should the amount of coal raised eventually reach 20,000,000 of tons, the period of its duration will be proportionably shortened. Various estimates of the duration have been made, of which a summary is given by Mr. Fordyce. One authority, Mr. Greenwell, calculates the period at 331 years. Mr. T. Y. Hall makes the period 365 years, and perhaps 400 years will prove a close approximation.*

This Coal-field contained in 1859, 183 collieries, producing 16,001,125 tons of coal.

There were in the same year 80 blast furnaces, of which 52 were in blast, producing 401,839 tons of pig-iron. In the year 1857 the number was only 69, so that the iron-trade appears to have undergone a great expansion, which, on the occurrence of a large demand, must lead to a greatly increased consumption of coal.

* See Appendix H. For further information see "Synopsis of the Newcastle Coal-field," by Mr. Buddle, Trans. Nat. Hist. Soc. of Northumberland, vol. i.

Coal-fields of the Borders.

Far down in the Carboniferous Limestone series of the North of England occur beds of workable coal, which in Scotland increase in number and economic value. They form coal-fields bordering the Tweed and its tributaries in Northumberland, and the Esk in Dumfriesshire. Though marked on the map as coal-fields, it is to be recollected that they are of much earlier date than the great coal-tracts of Durham and Yorkshire. The coal-seams underlie, for the most part, several thick beds of Carboniferous Limestone; and in turn repose on red sandstones of the Tweed. Mr. N. Wood has rightly referred these red sandstones, not to the Devonian, but to the Carboniferous period; for, as I am informed by Mr. Geikie, a thick series of Lower Carboniferous strata intervene between them and the true Old Red Sandstone of Scotland.

Mr. Wood,* who has given a full account of these Lower Carboniferous coals of Northumberland, states that they are worked at Talkin, Tindal Fell, Fourstones, Acomb, and Fallowfield. A very interesting section of the series is tabulated by Mr. Hutton from the Millstone Grit, down to the "4-feet seam" of Tindal Fell, for which I must refer the reader to the memoir itself.†

* Trans. Nat. Hist. Soc. Northumberland, vol. i.

† *Ibid.* vol. ii., p. 204.

CHAPTER XIX.

COAL-FIELDS OF SCOTLAND.

It will be observed, on looking at a geological map of Scotland, that the series of formations of which that country is composed, are arranged in bands crossing the island from south-west to north-east, and on the whole, parallel to the central range of the Grampian mountains.

The Carboniferous series of Scotland forms one of these bands, stretching from sea to sea, and occupying a trough between the southern slopes of the Grampians on the one side, and the indented flanks of an elevated district, composed of Old Red Sandstone, and Lower Silurian rocks, stretching from Kirkcudbrightshire to Berwick, of which the Lammermuir, Moorfoot, and Lead Hills form a part. The height of many of these hills is considerable. Merrick Hill reaches an elevation of 2751 feet, Cairns-Muir-of-Deugh 2597, Black Larg 2890,* and Black Hope Scar 2136 feet.

The western margin of the Carboniferous area is washed by the Firth of Clyde, and the river itself drains a large tract of the great central coal-basin. The eastern limit is the North Sea on both shores of the Frith of Forth. The northern boundary line passes

* According to the Geological Map of Scotland, by Prof. Nicol.

from Ardrossan, by Glasgow, Stirling, and Cupar. The southern boundary is extremely irregular, deeply indented by promontories of Lower Silurian, and Old Red Sandstone, which sometimes protrude to the surface, and divide the coal-formation into separate basins. At the same time the coal-strata have been deposited in bays formed in these older rocks. The extreme length from the coast of Ayr to Fifeness, is 94 miles. The average breadth, 25 miles.

This great range of Carboniferous rocks is not all productive of coal; hence the coal-bearing series forms several distinct fields or "basins," separated either by physical barriers, as friths and rivers, or by the uprising of the Lower unproductive Carboniferous or Devonian rocks from which the Coal-series has been swept away. These separate fields may be thus denominated. 1. The coal-field of the Clyde Basin. 2. Mid-Lothian and Haddington coal-field. 3. The Fifeshire coal-field. 4. The Clackmannan coal-field. 5. The Ayrshire coal-field. 6. The Lesmahago coal-field.

Geological Age of the Scottish Coal-fields.—By far the greatest part of the workable coal-series of Scotland is included in the Carboniferous Limestone group, while at the same time there are coal-seams referable to the Millstone Grit, and true Coal-formation of central England. Owing to denudation, this upper series is but sparingly distributed, forming the "flat coal-group" of the centre of the basins.

If we observe the gradual change which the Lower Carboniferous rocks of England undergo in their extension from the midland counties into Northumberland and South Berwickshire, we shall be prepared for their remarkable mineralogical character as developed in Scotland. In Derbyshire, the Carboniferous Limestone consists of an enormous mass of calcareous rocks once formed in a sea teeming with animal life, almost destitute of sedimentary material, and entirely so of coal. Further north, in Lancashire and Yorkshire, workable coal-seams are found at a stage earlier than the true Coal-measures—namely, in the Millstone Grit, associated with fossil shells allied to those of the Carboniferous Limestone. Still further north, the bold coasts of Northumberland exhibit the great limestone formation opening out into different courses, and including thick beds of shale, and several coal-seams; one of the calcareous bands, near the centre of the group, being characterized by *Posidonomya Becheri*, a fossil belonging to the "Calp" of Ireland, and the Culm limestone in Devonshire.* These coals of Northumberland have been shown by Mr. N. Wood to be situated near the base of the Carboniferous Limestone, and are worked over a considerable tract of country.† They occupy exactly the position of the Lower Coal-series of Scotland; but in this latter country, the sedimentary strata receive a great augmentation of volume, while the calcareous beds are proportionally diminished. Instead of the solid beds of limestone of Derbyshire, we find in the Lothians, and elsewhere, a thick series of sandstones,

* Murchison—"Siluria," 3rd edit., p. 311.

† Trans. Nat. Hist. Soc. Northumberland, vol. i.

shales, black-band ironstones, and coal-seams, with occasional beds of marine limestone, containing fossils of the Carboniferous Limestone period.

Trap Rocks.

The base of the Coal-formation of Scotland is the Old Red Sandstone; and at or near the junction there has been a very general outpouring of submarine lavas and ashes, which we now find consolidated into greenstone, felspar-porphyry, and tufa, in some places earthy and amygdaloidal. These are stated by Sir C. Lyell to constitute a ridge parallel with the Ochils, extending from Stirling to near St. Andrews, where they are very clearly exposed in the coast cliffs.* These bedded igneous rocks receive their highest exemplification in the bold escarpments of the Pentland Hills and Salisbury Crag. The really stratified character of these rocks has only recently been demonstrated by my colleagues, Messrs. Geikie and Howell, and is beautifully indicated in the new geological map of Edinburgh. It is here shown that they follow the dip and direction of the associated strata—all pointing to the conclusion that they have originally been poured out over the bed of the sea, at intervals, during the deposition of the

* "Elementary Geology," p. 561. One of the most remarkable forms which these rocks assume along the coast, is known as the "Rock and Spindle." It consists of a pinnacle of tuff which may be compared to a distaff, and near the base is a mass of columnar greenstone, in which the columns radiate from the centre like the spokes of a wheel. Readers of Burns will recollect that "the rock" is the Scotch name for a distaff.

Lower Carboniferous strata. Rocks of a similar origin occur amongst the Garlton Hills, and probably include many of the great protrusions, which are found at intervals along the whole course of the Scottish coal-field, from the mouth of the Frith of Forth to the coast of Ayrshire. They may always be distinguished from eruptive traps by their bedded character; and, as a general rule, the strata which overlie them are not altered or metamorphosed, as when brought in contact with eruptive dykes.

In contradistinction to these are the dykes of later date, injected along fissures in the strata, in which they produce well-marked changes; such as expelling the bituminous part of coal, and hardening sandstones and shales. Three dykes of this nature are mentioned by Mr. Milne, in the coal-fields of Mid-Lothian, called the "Niddry," "Morison's Haven," and "Cockenzie" dykes. The eastern part of the Fifeshire coal-field has also been invaded by masses of trap which have broken up, and injured the coal to a large extent.

General Succession of the Coal-series.

The whole of the coal-bearing strata of Scotland may be arranged under three great divisions, corresponding to the principal groups of the Carboniferous system of England, though under somewhat altered conditions. They are as follows:—

Upper Coal-series.—Representing the true Coal-measures of England, and frequently called the "Flat Coal Group." It consists of reddish sandstone, shales, fireclays, ironstone, and coal-seams. This group generally occupies the centre of the troughs or basins, where the strata are horizontal or nearly so—but owing to the denudation of the strata is not very widely spread. The fossil shells belong to the genus *Anthracosia*.

Millstone Grit.—A thick series of gritty sandstones, known as "Roslyn Sandstone," and "Moorstone Rock," with beds of shale, and a few bands of coal and limestone with marine shells, as *Spirifer*, *Productus*, also *Cyathophylla*, and *Encrinites*.

Lower Coal-series.—Sandstones, shales, marine limestones, ironstones, and coal-seams in considerable number and thickness. This group constitutes the most important portion of the Scottish Coal-field.

Underneath these come lower beds of marine limestones, and below them an enormous thickness of sandstones and shales, including the celebrated Burdiehouse limestone, and a few thin coals in the upper part, resting finally on the Old Red Sandstone.

The above classification is nearly that adopted by my colleagues of the Geological Survey in their Memoir on the Mid-Lothian Coal-field,* and applies generally to the whole of Scotland. With this general introduction I now proceed to give some special details regarding the coal-series in different parts of the country, commencing with the Clyde Basin.

District of the Clyde Basin.

This district extends from Renfrewshire to the Frith of Forth, and includes portions of the shires of Dumbarton, Lanark, Stirling, and Linlithgow. It is bounded on the north and west by broad sheets of trap, and

* "Geology of Edinburgh," Mem. Geol. Survey, by Messrs. Howell and Geikie.

through the centre rises an unproductive area of Lower Carboniferous Limestone. Along the south the coal-strata rest upon an indented ridge of Silurian slates, by which they are separated from the Lesmahago coal-basin.

The general succession of the coal-seams in Lanarkshire, is illustrated by a vertical section by Mr. Ralph Moore, of which the following is a synopsis:—

Upper Series.— 840 feet.	From the Upper Four-feet Coal downwards, with ten coal-seams from two feet and upwards in thickness; also with the "Palace Craig," the "Airdrie" and "Slaty" black band ironstones.
Middle Series.— 960 feet.	From the "Moorstone Rock," or Millstone Grit, down to the Garnkirk limestone.
Lower Series.— 2,200 feet.	Six courses of marine limestone from the Garnkirk bed downwards to that which overlies the Hurlet coal. Three courses of black-band ironstone, and several beds of valuable coal.

Mr. William Moore, in a valuable communication to the Philosophical Society of Glasgow, presents us with the following succession of the coal and iron beds of that part of the coal-field lying along the valley of the Clyde.

Coal and Ironstone Series in the Valley of the Clyde.

Depth. Fathoms.		Thickness. Ft.	In.
42	— *Palace Craig Ironstone* (impure)		
48	— Upper Coal (good)	3 to 4	6
63	— Ell Coal (good)	8	0
67	— Pyotshaw Coal (splint)	4	0
68	— Main Coal (good, soft quality) ..	3½ to 5	0
76	— Humph Coal	I	8
81	— Splint Coal (for iron smelting)	3	0
84	— Sour Milk Coal (variable)	3	0
103	— *Mushet Blackband Ironstone*	1	4
106	— *Soft Band Ironstone*	1	8

Depth. Fathoms.		Thickness. Ft.	In.
120	— *Curly Band Ironstone*	0	5
127	— Virtue Well Coal	2	6
132	— *Bellside Ironstone*	0	7
134	— *Calderbrae Ironstone*	0	8
136	— Kiltongue Coal (variable)	5	0
148	— Drumgray or Coxrod Coal	2	0
203	— *Slaty Blackband Ironstone*	1	6
„	— Boghead Gas Coal (1 to 20 inches) ..	0	10
447	— *Possil Ironstone*	1	0
467	— Lesmahago Gas Coal	1	0
502	— *Govan Band Ironstone*	1	0

The "Boghead coal," in the county of Linlithgow, the object of a celebrated trial at law, and one of the most valuable of the brown cannels of Scotland, occurs in a small area, and is of an average thickness of 18 inches, but reaches in some places 30 inches. It is a true coal, as it rests on a bed of fire-clay full of *Stigmaria*, and is surmounted by shale and ironstone with plants and shells (*Anthracosia*). It yields about 70 per cent. of volatile matter, and is in high request for the manufacture of paraffine oil.

Mr. Moore sums up as follows:—The workable coal-seams are ten in number, viz., the Upper, Ell, Pyotshaw, Main, Humph, Splint, Sourmilk, Virtue Well, Kiltongue, and Drumgray seams. They are all valuable for household and manufacturing purposes, and in these seams, the total available quantity still to work is about 424,620,700 tons. Taking the present annual produce of the district under consideration (between the Friths of Forth and Clyde), at 3¼ millions of tons, this quantity of coal would last 130 years.*

* Trans. Glasgow Philosophical Society, 1860.

The number of ironstone bands described and shown in this section is 12. Of these the principal are seven in number: the Mushet Blackband, the Roughband, the Bellside, Calderbrae, Slaty, Possil, and Govan Blackbands. The quantity of ironstone in these seams, within the area of this district, amounts to about 72,081,400 tons in the calcined state. This quantity will supply all the iron-works in the district, comprising nearly 100 blast furnaces, for about 72 years, supposing them to continue in full operation as heretofore, and to consume as at present, one million of tons of calcined ironstone yearly.

Fossil Remains.

Mr. J. Craig has classified the fossils in this district as follows.*

In his "Upper Fresh-water" series, comprehending the strata from the Millstone Grit upwards, there occur several species of *Anthracosia* (*Unio*) and fishes, as *Megalichthys Hibberti*, *Gyracanthus formosus*, *Ctenachanthus*.

In his "Upper Marine" series, the limestones contain *Encrinites*, *Nucula*, *Bellerophon*, *Euomphalus*, *Orthoceras*, &c.

Coal-field of Mid-Lothian and Haddington.

This coal-field consists of a double trough, the deeper of which lies in Edinburghshire on the west, and the shallower in Haddington on the east.

The western boundary is the Pentland Hills, along

* Brit. Assoc. Rep. 1840.

the base of which the Carboniferous strata plunge rapidly towards the centre of the trough. The axis of the trough lies nearly north and south, passing through Dalkeith. On approaching the Carberry ridge the beds again rise and crop out, and the Roman Camp limestone forms a ridge dividing the two troughs. On the east of the Carberry ridge the lower coal-seams again roll in, and form the wide trough of Haddington, where the beds lie in a position not much removed from the horizontal.

To the north of these troughs, the coal-seams strike out to sea, are overspread by the Frith of Forth, and re-appear on the opposite coast of Fifeshire.

The thickness of the Coal-series in the Lothians is, according to Mr. Milne, upwards of 1000 fathoms, consisting of sandstone 286 fathoms, of shales 188, of limestone 27, of clay 12, and of coal 21 fathoms. There are from 50 to 60 coal-seams of greater thickness than one foot, the thickest being 13 feet.*

My colleague, Mr. Howell, arranges the Coal-series into three groups corresponding to that given above or the Coal-formation of Scotland generally.† The total thickness is 3,150 feet exclusive of the Lower Carboniferous series, which has little or no workable coal:—

		Feet.
1 Coal-measures (flat coal group) ..	..	1,220
2. Millstone Grit	..	340
3. Carboniferous Limestone Series	..	1,590

These formations pass gradually into each other, and

* "Coal-fields of Mid-Lothian." Trans. Roy. Soc., Edinburgh.
† "Geology of Edinburgh." Memoirs of the Geol. Survey.

are quite conformable. The Coal-measures (No. 1) are confined exclusively to the western trough, and do not occur in Haddington. The faults generally range from east to west, transversely to the axis of the troughs.

The workable coal-area as measured from the maps of the Geological Survey is 64 square miles.

Coal-series of Mid-Lothian.

Taken from the centre of the trough near Dalkeith.

		Feet.	In.
Coal-measures, 1220 feet.	*Sandstone and Shale*	346	0
	Clay Knowes Coal	3	6
	Splint Coal	3	10
	Beefie Coal	3	6
	Jewell Coal	4	0
	Coal	2	8
	Cowpits Little Splint	2	2
	Cowpits Five-feet	5	6
	Glass Coal	2	0
	Barrs Coal	4	0
	Cowpits Three-feet	3	0
	,, Six-feet	4	6
	Millstone Grit	340	0
Carboniferous Limestone Series, 1590 feet.	Cowden Deception Coal	2	2
	,, Cryne	2	6
	,, Mavis	2	8
	,, Great Seam	8	0
	,, Diamond	2	7
	,, Lilla Willie	5	1
	,, Blackbird Seam	3	11
	,, Coronation	3	10
	,, Hard Splint	3	3
	,, Smithy Coal	2	9
	,, Bryant's Splint	5	8
	,, Aleck's Coal	2	7
	,, Coal	2	6
	,, Little Splint	2	1
	,, Coal	2	1
	,, Parrot Seam	3	0
	Chalkieside Lime Coal	3	0

The above include only coals of 2 feet and upwards. There are altogether no less than 46 seams with an aggregate thickness of 122 feet of coal. There are also 9 seams of ironstone of 2 inches and upward.

The principal coals are "the Great Seam," which has been traced from its outcrop at Gilmerton, under the valley of the Esk, over the Carberry ridge, to the valley of the Tyne, a distance of 12 miles. It extends from the flanks of the Lammermuir range northward to the sea. Below this, at a depth of 250 fathoms, is the "North Greens" coal, which yields the "Parrot-coal," valuable for its gas.

Mr. Geikie describes in detail the structure and organic productions of the celebrated Burdiehouse limestone, and arrives at the conclusion that it was slowly elaborated at the bottom of an estuary of a river into which the remains of terrestrial plants were drifted from the land, while bone-covered fishes haunted the waters, and huge sharks (*gyracanthus*) ascended from the sea to share in the decaying putrescent matter ever brought down from the interior.*

Resources of the Coal-fields of the Lothians.

Mr. Milne in 1839 gave the following estimate of the mineral resources of this district:—

Upper Group	710	millions of tons.	
Two Lower Groups	5,000	"	"
	5,710	"	"
Deducting for loss, and the quantity worked out, this is reduced to about	2,250	"	"

* "Story of a Boulder."

Taking the yearly produce at 390,000 tons, there has been raised in the twenty-two past years since 1839, about 8¼ millions of tons, which, deducted from the above, leaves for future supply 2,241 millions of tons.

Fifeshire Coal-field.

This coal-field is of considerable extent and of great mineral productiveness, but is over a large area of its eastern part, much dislocated by faults, and destroyed by the intrusion of igneous rocks. Nearly the whole of the coal-seams enter the sea between Kirkcaldy and East Wemyss, and present the following section as given by Mr. Landale in his valuable memoir.*

Coal-series of Fifeshire.

	Ft.	In.
1. Parrot Seam	2	6
2. Pilkembare Coal ..	2	0
3. Wall ,, ..	3	0
4. Barn Craig ,, ..	5	6
5. Upper Coxtool Coal	3	0
6. Lower ,, ,, ..	3	6
7. Den Coal	2	2
8. Main or Chemis ..	9	0
9. Bush Coal	3	6
10. Parrot ,, ...	2	3
11. Wood ,, ...	3	0
12. Earl's Parrot Coal ..	2	0
13. Bowhouse ,, ..	6	6
14. Brankston ,, ..	4	0
15. Coal Moro ,, ..	2	6
16. Coal Mangey ,, ..	2	6
17. Boreland Coal ..	3	6
18. Sand Well ,, ..	3	0
19. Dysart Main Seam ..	21	0
20. Dysart Lower Seam ..	7	0
21. Dunnikier Five-feet Coal	2	6
22. Four-feet Coal ..	4	0
23. Three-feet ,, ..	3	0
24. Black and Parrot Coal	5	3
25. Upper Smithy ,,	3	0
26. Lower ,, ,,	1	6
27. Parrot Seam Coal	2	0
28. Coal Seam	2	4
29. Invertiel Coal ..	5	6
Total thickness of Coal	120	6

The Invertiel coal overlies a thick and very constant bed of limestone which forms the physical base of the coal-producing strata. Underneath this limestone is a thick series of Lower Carboniferous rocks, the coal-seams of which are not of economical value.

* Trans. Highland Society, vol. x.

Clackmannan Coal-field.

This coal-field is separated from that of Fife by the uprising of the Lower Carboniferous rocks near Dunfermline. It stretches along the northern and eastern banks of the river Forth, by which it is separated from the great central coal-field of the Clyde Basin.

Ayrshire Coal-field.

The Ayrshire coal-field stretches along the coast from Ardrossan to the mouth of the river Doon, and extends inwards to the base of the hills of trappean and Devonian rocks, by which it is separated from the coal-field of the Clyde basin. It is a rich and productive district, large quantities of coal being shipped from Ayr, Troon, Irvine, and Ardrossan.

Upper Lesmahago Coal-basin.

To the south of the central mass of Carboniferous rocks are several detached outliers, separated by the older Palæozoic rocks. The principal of these are the Lesmahago and Muirkirk Coal-basins in the county of Lanark. The Carboniferous series, as shown by Mr. Geikie, here rest upon the Lower Old Red Sandstone to which they are unconformable. The following are sections of the Coal-series curtailed from those of Mr. Slimon.*

* From Appendix to Sir R. Murchison's paper on the "Lesmahago Silurians" in Journ. Geol. Soc., vol. xii., p. 25. The Geological features of this district are also described by Mr. Geikie. *Ibid.*, vol. xvi. As these pages were passing through the press, Mr. Williams, Her Majesty's Inspector, kindly procured for me details regarding the Upper and Lower Lesmahago Coal-basins, of which I can only insert a small portion.

Section at Coal Burn.

	Ft.	In.
Shale and Limestone ..	10	0
Sandstone and Shale ..	27	0
Gas and Dross Coal ..	1	0
Sandstones and Shales ..	25	0
Dross Coal	3	0
Fire-clay	0	11
Dross Coal, with 6 inches of Horn Coal	3	11
Strata	13	0
Coal	8	0
Fire-clay	3	6
Coal	2	9
Strata	12	0
Blackband Ironstone ..	0	8
Shales with Ironstone ..	7	4
Smithy Coal	1	6
Fire-clay	1	6
Coal	4	0
Stone	0	7
Coal	4	7
Shales, with seams of Ironstone	81	8
Coal, with 6 inches of stone	6	0
Strata, with Ironstone	54	0
Coal (stinking)	5	0
Sandstones and Shales ..	34	0
Limestone	1	8
Grey Shale	20	0
Ironstone	0	8
Shale and Limestone with *Productus*	46	0
Sandstone and Limestone resting on upper Old Red Sandstone.		

Section at Auchenheath.

	Ft.	In.
Shales and Sandstones.		
Limestone	1	6
Shale	10	0
Strata, with four beds of Limestone	225	3
Smithy Coal	1	4
Shelly Clay	1	6
Coal	4	0
Strata	15	0
Gas Coal	0	10
Blackband Ironstone ..	0	5
Shales with Ironstone balls	3	8
Coal	0	8
Fire-clay	1	6
Dross Coal	3	0
Shales and Sandstones ..	54	6
Coal	0	10
Shale	5	0
Gas Coal	1	9
Ironstone	0	4
Fire-clay	1	3
Coal	0	6
Sandstone resting upon Limestone.		

These beds are supposed to rest upon Old Red Sandstone.

This coal tract is about 7½ miles from E. to W. and from N. to S. Mr. J. Ferguson states that three-fourths of its area is stored with coal of second-class quality. There is at Ponfrich an aggregate thickness of 53 feet of coal in a vertical depth of 200 fathoms. The Lower Lesmahago Coal-field forms a part of the Great Central Coal-field of the Clyde Basin.

CHAPTER XXI.

BRORA COAL-FIELD, SUTHERLANDSHIRE.

A SMALL coal-field occurs at Brora, near the shores of Dornoch Firth. It has been shown by Sir R. Murchison to be of the age of the Lower Oolite, and in all probability contemporaneous with the carbonaceous strata of Whitby in Yorkshire. The following is part of the section of one of the pits from which the coal was extracted :—

	Ft.	In.
13. Dark argillaceous schistus with soft partings and a few shells	36	6
14. Very large-grained sandstone, with shells and wood (coal-roof)	5	0
15. Fine cubical coal, burning to white ash ..	3	8
16. Bituminous shale, containing natural oil, burns, but does not consume	2	0
17. Slate-coal with pyrites	1	4
18. Fire-clay and argillaceous schistus	90	0

The coal-bed appears to be at or near the base of the Great Oolite, as in Yorkshire, but the Inferior Oolite would appear to be absent, if the thick bed of shale belongs (as is probable) to the Upper Lias. The shells enumerated by Sir R. Murchison from the beds above the coal, are typical of the formations from the Great Oolite to the Calcareous Grit.

The first pit was opened in 1598 by the Countess of

Sutherland. That now in use was sunk in 1814, and up to the year 1827 seventy millions of tons of coal had been raised.*

Skye.—In the Isle of Skye is a small coal-field, probably of Lower Oolitic age, which contains a bed of coal nearly 5 feet in thickness.

Resources of the Scottish Coal-fields.

1. The area of workable coal, including 46 square miles belonging to the Lothians.†	1,720 square miles.
2. Average thickness of workable coal above two feet	15 yards.
3. Total original quantity of coal (corrected for denudation) not including that of the Lothians	38,472 millions of tons.
4. Deduct for loss, and quantity already extracted one-third, leaving	25,648 " "
5. Deduct for quantity below 4,000 feet in depth one-tenth, leaving	23,038 " "
6. Add quantity in the Lothians	2,240 " "
7. Total available quantity 23,083+2,240=	25,323 " "

Which at the present rate of consumption of 10,300,000 tons, would last for 2,450 years.

CHAPTER XXII.

IRELAND.

THAT Ireland was once covered over two-thirds of its extent by coal-beds is a proposition which we may confidently affirm on geological grounds; but the misfortunes of the sister isle began long before the landing of

* Trans. Geol. Soc. London, vol. ii.

† Mr. D. Milne, and Mr. J. Nicol.—I have given the estimate of Mr. Milne (after deducting the quantity raised since his estimate was formed) for the coal-fields of the Lothians separately.

Strongbow, for old father Neptune has swept the coal and coal-strata clean into his lap, and left little but a bare floor of limestone behind. In plain words, if we examine a geological map of Ireland, we shall find that the Carboniferous Limestone overspreads its greater part; and as we always find in England that this formation is ultimately surmounted by Coal-measures, so we may infer there was the same order of succession here, before the sea—which more than once overwhelmed the country after the Carboniferous epoch—remorselessly swept away the most valuable portion of this system of rocks, with the exception of a few isolated tracts now about to be described.

Mr. Jukes, who, with his staff of geological surveyors, is engaged in working out the geology of Ireland, gives the following as the succession of the Carboniferous rocks:*

Coal-fields of Kerry, Cork, and Waterford.

2. Coal-measures.—Shales and cleaved slates, fine-grained grits, with thin coal-seams, more than	2,000 ft.
1. Carboniferous Limestone	1,500 „
Old Red Sandstone.	

The Coal-measures are generally highly inclined, contorted, or inverted, and the beds of coal have been so compressed as to be only a few inches in thickness for many yards, and then suddenly expand into large pockets of coal of a thickness of 20 or 30 feet. Coal-mining is here conducted like vein-mining, and the Coal-measures are of the age of the Upper Limestone Shale of England.†

* "Manual of Geology," p. 445.

† Map of the Geol. Survey of Ireland, 152 with "Explanation."

Clare, Limerick, Tipperary, and Kilkenny.

5. Coal-measures.—Similar to those in Cork, but generally lying nearly horizontal. The coals retain their original thicknesses, varying from 6 inches to 3 feet. Coal-plants are abundant, and shells, which in England belong to the period of the Millstone Grit or Gannister beds, as *Goniatites*, *Bellerophon*, *Pecten papyraceus*.
4. Upper Limestone.—Crystalline and compact limestone.
3. Calp or Middle Limestone.—Black limestones and shales.
2. Lower Limestone.—Thick-bedded grey limestone, sometimes crystalline, and often dolomitic and oolitic.
1. Lower Limestone shale.

The following is the general series of coals in the Castlecomer coal-basin, by Messrs Jukes and Kinahan.*

		Ft.	In.
	Uppermost beds, about	12	0
6.	*Peacock Coal*	1	10
	Strata	45	0
5.	*Stoney Coal*	3	0
	Strata	21	0
4.	*Double Seam*	5	0
	Strata and shales with *Myacites* (Anthracosia ?)	120	0
3.	*Three-feet* or *Old Colliery Coal*	3	0
	Strata	180	0
2.	*Foot Coal*	1	6
	Strata	300	0
1.	*Gale Hill Coal*	0	6
	Flag Series, about	650	0
	Black Shale Series	500	0
	Upper Carboniferous Limestone.		

Throughout the whole of the Coal-measures shells have been found; and the black shales at the base are stored with crushed specimens of the genera *Aviculopecten*, *Euomphalus*, *Bellerophon*, *Goniatites*. There are also remarkable crustacea, somewhat resembling those

* Explanation of Map 137 of the Geol. Survey of Ireland, p. 10.

of Coalbrook Dale in Shropshire, figured and named by Mr. W. H. Baily, *Bellinurus Regina.**

Fossil-plants of the usual Coal-measure genera are abundant, such as *Calamites, Lepidodendron, Sigillaria,* with its rhizome, *Stigmaria ficoides.* The coal-beds also invariably repose on floors of underclay.

However similar in its features this coal-series may appear to those of England, there is no doubt it is of an earlier period than the true Coal-measures, and may probably be placed in the horizon of the Millstone Grit, or Yoredale series.

North of Ireland.—Tyrone, Ballycastle, &c.

In this part of Ireland the Coal-measures appear to belong to the age of those of England, and are underlaid by Millstone Grit. The inferior beds are similar to those above described.

From the survey of Sir R. Griffith, it would appear that the Tyrone coal-field is rich in minerals, though of limited extent. Along the banks of the river Torrent seven workable beds of coal appear, having a combined thickness of 30 feet, and included within 280 yards of strata, which are ultimately covered over by red sandstones and marls, probably of Triassic age.†

The *Tyrone Coal-field* is situated in the Barony of

* Explanation of Map 137 of the Geol. Survey of Ireland, p. 12. See also Vertical Sections of Collieries in this coal-field, published by the Geol. Survey of Ireland, sheet 1.

† Geological and Mining Surveys of Tyrone and Antrim. Dublin, 1829.

Dungannon, and a few miles to the west of Lough Neagh. It is of trifling extent when compared with the great Southern and Western Coal-districts of Ireland, but it is superior to them in the thickness and quality of its numerous beds of coal.

The general succession of the formations are as follows :—

1. Trias ?—Red sandstones and marls, resting unconformably upon the coal-formation.
2. Coal-measures.—Alternating beds of black shale, sandstone, argillaceous ironstone, fire-clay, and coal.
3. Limestone Shale.—Consisting of sandstone, limestone, and shale with thin beds of coal.
4. Carboniferous Limestone.—Massive limestone, passing upwards into a series of alternating beds of sandstone, shale, slaty limestone with coal.
5. Old Red Sandstone.—Red sandstone, &c.

The coal-field is divided into two parts, namely, the Coal Island District, and the Annahone District.

The Coal Island District is six miles long, its average breadth is about two miles; therefore, the total extent may be about seven thousand acres.

The Annahone District is much smaller. It is one mile long, and half a mile broad. It may, therefore, contain 320 acres. Mr. Griffith states, however, that it is probable the district may extend a considerable distance further to the south and east, and that coal may be wrought from beneath the Red Sandstone. The coal-field is, moreover, covered to a considerable depth with drift deposits, which render the strata difficult of access.

The following is some account of the coal-seams in descending order :—

	Yards.	Feet.	In.
Upper Coal (impure)	0	2	2
Strata	12	1	0
Annagher Coal (soft quality)	0	9	0
Strata	18	1	0
Bone Coal	0	3	0
Strata	13	0	0
Shining Seam	0	2	10
Strata	26	0	0
Brackaveel Coal (good quality) ..	0	4	6
Strata	28	0	0
Baltiboy Coal (sulphureous)	0	3	0
Strata	24	0	0
Gortnaskea Coal {Cannel .. 2 feet; Coal .. 4 „}	0	6	0
Strata .. .. (about) ..	75	0	0
Derry Coal (good quality)	0	4	6

Below these there are two or three other seams. Most of the coals are of good quality, and have not, as yet, been worked to any great depth.

Antrim Coal-District.

The Antrim coal-district, in point of geological position, is by much the most remarkable in Ireland. It is situated on the north coast of the county, and extends to the west and south of the magnificent promontory of Fair Head from Ballycastle to Murlough Bay, a distance of four miles. Its average breadth is one mile and a half.

The general arrangement and succession of rocks which compose the coal-formation of the district, is finely exposed to view in the range of precipitous cliffs which stretches from the Salt Pans, east of Ballycastle, to Murlough Bay. Throughout this line of coast, the coal-strata are in some places surmounted by masses of basalt, presenting towards the sea ranges of vertical columns. In other parts, the beds are bent, faulted, and traversed by several dykes of greenstone.

A good section of the beds is visible in the cliffs near the Gob mine, exhibiting a height of strata amounting altogether to 373 feet, of which 51 feet at the summit consist of imperfectly columnar trap, and the remainder is composed of alternating beds of coal, sandstone, shale, and limestone. The main bed of coal is 4 feet thick.

The following is the section visible on the northern side of Murlough Bay from the top of the cliff downwards:—

Section in Murlough Bay.

	Feet	In.
Columnar Greenstone (about)	100	0
Brownish-red Sandstone	20	0
Bituminous Coal	1	0
Red Sandstone	80	0
Black Shale	6	0
White Mine Coal (highly bituminous) ..	2	6
Brownish-red Sandstone	40	0
Bituminous Coal	0	6
Red Sandstone	20	0
Black Shale	10	0
Bituminous Coal (Goodman's Vein)	2	6
Black Shale	60	0
Uninflammable carbonaceous Coal	2	6
Black Shale passing into flinty-shale ..	2	0
Second columnar Greenstone (basalt) ..	70	0
Black Shale	2	0
Non-flaming Coal, with thin beds of black Shale	8	6
Black Slate (base not visible)	10	0
	437	6

It appears from the foregoing section, that the coal-formation at Murlough Bay contains six beds of coal, four of which are highly bituminous, and two wholly carbonaceous, or anthracitic. The four bituminous beds all occur between the first and second basaltic ranges, and the two carbonaceous beds are nearly in contact, one above, and the other beneath the second basaltic range. The general base of the coal-formation of the Antrim coast is probably mica slate.

The early workings in the coal-mines of Ballycastle have already been alluded to.

The coal of the greater part of the Irish Coal-measures is anthracite, as the well-known Kilkenny coal. The produce of all the collieries, numbering 45, for 1859, was as follows:—

	Tons.
Anthracite and small coals	78,250
Bituminous Coals	42,150
Total	120,400

CHAPTER XXIII.

SUMMARY OF RESOURCES.—GREAT BRITAIN.

THE following is a synopsis of the results arrived at in previous chapters:—

Name of Coal-field.	Area Square Miles.	Quantity of Coal to a depth of 4,000 ft.	Overspread by formations newer than the Coal-measures.	
			Area sq. miles.	Quantity of Coal to a depth of 4,000 feet.
		Millions of tons.		Approximate Milns. of tons.
1. Anglesea	9	inconsiderable	..	..
2. Bristol and Somerset	45	746	105	1,742
3. Coalbrook Dale ..	28	28	..	..
4. Cumberland ..	25	97	..	..
5. Denbighshire ..	47	490	20	412
6. Derby and Yorkshire	760	8,800	400	8,000
7. Durham & Northumberland	460	4,270	225	3,000
8. Flintshire	35	20	uncertain	..
9. Forest of Dean ..	34	561	..	..
10. Forest of Wyre ..	..	inconsiderable	..	..
11. Lancashire	217	4,010	25	500
12. Leicestershire ..	15	50	30	400
13. North Staffordshire .	75	1,618	20	619
14. South Staffordshire.	93	973	..	..
15. Shrewsbury	..	inconsiderable	..	..
16. South Wales ..	906	16,000	..	..
17. Warwickshire ..	30	417	107	1,767
ENGLAND AND WALES ..	2,779	38,080	932	16,440
SCOTLAND	1,720	25,323	..	..

From the above calculations we obtain the following results:—That in Great Britain there is a total area of

2,779+932+1720=5,431 square miles stored with coal to a depth of 4,000 feet. And that the quantity of available coal within the same horizontal and vertical limits is 38,080+16,440+25,323=79,843 millions of tons. These are the broad *tangible results.*

This quantity is sufficient to sustain the present supply, of nearly seventy-two millions of tons, for upwards of a thousand years without exhaustion. But as the supply is liable, from a variety of causes, to progressive increase, we shall in a future page* proceed to consider the questions of the probable yearly rate of increase, and of the length of time during which the British Coal-fields will be capable of meeting this augmenting drain on their resources.

* See chap. ii., Part IV., p. 230.

PART III.

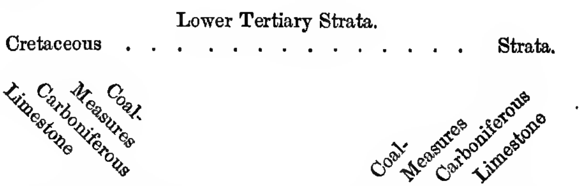
CHAPTER I.

COAL-FIELDS OF EUROPE.

France and Belgium.—The Coal-formation of these countries extends in a long and narrow trough from Aix la Chapelle westward, by Liege, Namur, Mons, and Valenciennes, at which place it is concealed beneath nearly horizontal beds of Cretaceous and Tertiary rocks. West of this town, however, the coal has been proved to a distance of 80 miles; and again reaches the surface a few miles north-east of Boulogne. Here the dip is north, and the Carboniferous Limestone rises from below the Coal-measures. There is every reason to believe that this is a prolongation of the same trough which enters beneath the Cretaceous strata at Valenciennes. Before reaching the sea at Calais, the Carboniferous strata are concealed by Lower Oolite, and nowhere reappear across the south of England till we reach Somersetshire.

The coal-trough is not everywhere continuous, being dissevered into elongated basins east of Mons, by the elevation of the Lower Carboniferous beds. These latter themselves, as in the north of England, sometimes contain coal which has been mistaken for that of the true Coal-formation; and at Liege and Mons the strata are repeatedly crumpled, and thrown into a vertically zig-zag position, so that the same shaft passes several times through the same seam of coal. We have analogous cases along the northern flanks of the Mendip Hills in Somersetshire, but not so generally known. The whole length of the trough, measured from Aix la Chapelle to Calais, and considered as continuous, is about 210 miles; but the breadth is variable, and never great.

The united extent of these coal-fields is probably nearly 1200 square miles; but there is a considerable tract between Valenciennes and Calais, overspread by Chalk and Tertiary formations, under which the Coal-measures have not yet been proved, and where they lie at considerable depths.* The general arrangement of the strata in this part of their course may be thus expressed:—



I shall now state the names of the towns and villages situated along this trough, from west to east, taking as

* MM. Dufrénoy et Elie de Beaumont, Carte Géologique de la France.

a guide the map of M. A. Dumont.* Commencing at Lillers in Artois, it ranges by Bethune, Douai, Valenciennes, Condé, Mons, Namur, Huy, Liege, Aix la Chapelle—where the strata are folded into several distinct troughs; and about ten miles east of this town the Coal-measures become entirely concealed beneath the alluvial plain of the Rhine. Their course beneath this plain would appear to be north-east, by Juliers and Kaiserwerth, to the Valley of the Rhur, at the margin of the coal-field of Westphalia.

The depth of the Liege coal-basin at Mont St. Giles, according to Herr Von Oeynhausen, reaches to 3,809 feet below the surface, and the coal-basin of Mons is fully 1,865 feet deeper still.† But this is small in comparison with the depth attained by the strata in the Saarbrück coal-field.

There are several other small coal-fields surrounding, and planted within the great central plateau of France, of which the following are the principal:—

St. Etienne, about 15 miles long by 6 broad; St. Germain, Auzon, and Donjon.

Rhenish Provinces.—The coal-field of Rhenish Prussia is one of the largest in western Europe. It has an area of about 900 square miles, and stretches from Saarbrück on the W. S. W., to Kreutznach on the E. N. E., a distance of 50 miles, with an average breadth of 20 miles.

Along its northern edge it rests upon the Devonian

* Carte Géologique de le Belgique.

† Humboldt's "Cosmos." Sabine's Trans. Note 125.

Slates of the Hundsrück—the general dip being southward, in which direction the Coal-measures pass below the sandstone of the Vosges, and Permian beds. There are extensive intrusions of igneous rocks, especially along the northern outcrop, which detract from the mineral value of the district affected by them.

According to the observations of Herr Von Dechen,* the thickness and depth of the Coal-measures in the Saarbrück basin is very great. From several measurements it was found that the lowest coal-strata known in the district of Duttweiler, near Bettingen, descend to a depth of 20,682 English feet, or 3·6 geographical miles below the level of the sea. This is a depth below the sea equal to the height of Chimborazo above it; and at this depth the temperature may be inferred to range as high as 467° Fahr.

This coal-field is remarkable for having yielded the remains of several species of reptiles, discovered by Mr. Leonard Horner, and named by Professor Goldfuss *Archegosaurus*, having characters intermediate between the Batrachians and Saurians.†

Westphalia.—The Carboniferous rocks, which east of Aix la Chapelle are lost beneath the Upper Tertiary strata of the Valley of the Rhine, re-appear on the right bank of that river in Westphalia, north-east of Dusseldorf. Whether the Coal-measures themselves actually underlie the Rhine valley, is uncertain; but

* "Cosmos." Sabine's Trans. Note 125.

† Lyell, Elements of Geology, p. 53, 5th edit., and Journ. Geol. Soc., vol. iv.

assuming this to be the case, I have already stated the line it would be found to occupy.

The coal-field lies along the Valley of the Rhur. It is of a triangular shape, lying nearly east and west. Its greatest transverse diameter is 16 miles, and its length about three times this distance. But the visible breadth and length is much less than the actual, as the coal-field extends far below the Cretaceous strata to the northward, and coal is now being worked by shafts sunk through these newer formations.*

The Coal-field of Bückeburg, in Hanover, is of peculiar interest, being referable to the Cretaceous period as determined by Sir R. Murchison.

In Silesia there are coal-fields, apparently of considerable area, extending from the Riesen Gebirge eastward and westward into Bohemia. The coal is bituminous, and along with iron is vigorously worked.

Spain.—The coal-field of Asturias, along the southern shores of the Bay of Biscay is, as I am assured by Mr. R. Hunt, of considerable extent and capability, though at present but little opened up. The coal belongs to the Lower Carboniferous series.

M. Shultz, Director-General of Mines, states that the coal-basin of the centre of the Asturias forms a most extensive district, having more than sixty seams of coal, generally of the best quality, approaching to a vertical position, and extending several leagues from west to east. The eastern limit of the coal-tract appears to be Santander; and westward, probably Cape Ortegal. The

* Murchison and Sedgwick. Trans. Geol. Soc., vol. vi.

strike of the rocks is parallel to the axis of the Pyrenees; and near the eastern extremity of the range, on the southern flanks north of Ripoll, coal is extracted from beds which would appear to be an extension of those which yield that mineral in Asturias.

In Portugal, a small coal-field occurs at Vallongo, near the mouth of the Douro. The strata associated with the coal contain carboniferous plants, such as *Pecopteris* and *Neuropteris*. This district has been described by the late Mr. D. Sharpe, who was in all probability incorrect in referring this coal-field to the Silurian period.*

Mr. Sharpe gives the following section of the coal-series in this district:—

1. Red Sandstone with beds of dark carbonaceous shale.
2. Coarse conglomerate.
3. Coal-seam, 6 feet thick.
4. Conglomerate and shale, with a thin coal-seam.
5. Coal, four beds from 2 to 5 feet in thickness, resting on black shale. This is the principal seam of the district.
6. Shales with chlorite.

The "Brown Coal" formation of the Lower Rhine and the Alps, is considered by M. Von Buch to be of Miocene age. The quality of the lignite which it yields is extremely variable, both in quality and quantity. In some places the seams attain a thickness of several feet; and near Bonn the associated shales are used for the production of alum.

Bohemia.—According to the accounts of M. Michel Chevalier,† nature has left to Bohemia a rich dowry of

* "On the Geology of Oporto, &c." Journ. Geol. Soc., vol. v.

† *Sur les richesses de la Bohême en combustibles fossiles.* Annales des Mines, tom. i.

mineral fuel. Besides the older coal-bearing strata, there are very extensive areas underlaid by lignite of excellent quality, now worked in the north-western districts.

M. Chevalier considers that the coal-formation belongs to two different ages; that of Eastern Bohemia to the Lower Permian or Rothe-todte-liegende; that of Western to the true Carboniferous system. The former extends in a band along the base of the Chaîne des Géants (Riesen Gebirge). This band is probably connected with the coal-formation of Silesia.

The western formation is distributed into three basins. 1st, that of Rakonitz; 2nd, that of Radnitz; 3rd, that of Pilsen. Of these, the basin of Rakonitz is the most extensive.

The flora of Rakonitz and Radnitz, described by M. Stur and Count C. Sternberg respectively, consist of about 21 genera of carboniferous plants.

Russia.—The coal-fields of Russia are considered by Sir R. I. Murchison to belong to the Lower Carboniferous period.* They are included in a set of strata which has a very extensive range, but is only at intervals productive of valuable coal-beds. These carboniferous rocks form a narrow band along the western base of the Ural Mountains, from the Arctic Sea to lat. 51° S., plunging generally at high angles towards the west, and containing coal, here associated with sandstones, representing probably the "Millstone Grit" of England. On reaching the river Ural, they are concealed beneath the Permian formation, which laps over their edges, but

* "Russia and the Ural Mountains," vol. i., p. 69.

they re-appear again in Central Russia, occupying large areas in the governments of Riazan and Moscow, and stretching northwards to the White Sea, a distance of nearly 900 miles. Throughout this region they are only locally productive.

The following is the general succession of the Carboniferous series in Russia :—

Millstone Grit.——Represented along the Western flanks of the Ural range; beds of siliceous grit, shales, and coal-seams.

Goniatite Grit.——Either below or equivalent to the above; calcareous grits and shales, with traces of coal.

Upper Limestone.—Beds of limestone and shale, with traces of coal; characteristic shell being *Fusulina cylindrica.*

Middle Limestone.—Without coal, in the Northern region, with a little coal of good quality in the Southern Steppes; characteristic shell, *Spirifer Mosquensis.*

Lower Limestone.—Without coal in the North, with coal in the Southern regions; characteristic shell, *Productus giganteus.*

Sandstones and Shales.—With coal in the Northern region.

The coal-seams of the Moscow basin are generally impure, pyritous, and fragile, and seldom equal in quality to the best lignites of the Tertiary age in the Alps. Some of the seams are from 3 to 6 feet in thickness, and as they outcrop in natural ravines, are easily accessible. The coal-field between the Dneiper and the Don, north of the Sea of Azof,† is considered by Sir R. Murchison to be by far the most valuable in Russia. This tract has a length from W.N.W. to E.S.E. of 230 miles, and its transverse diameter is 100 miles. Its

* "Russia and the Ural Mountains," vol. i., p. 60.

† Generally known as the "Coal-field of the Donetz."

total area is about 11,000 square miles. It contains many valuable beds of coal, which dip under and are overspread to the north-east by cretaceous rocks, and to the south-west by Permian limestone (Zechstein), under both of which formations the coal may at some day be mined, as is the case in Belgium and England. The most valuable seams occur at Lugan and Lissitchia-Balka.

It is a most remarkable circumstance in connection with the formation of the Donetz, that the same beds of coal from being highly bituminous in the western parts of this coal-field, pass by imperceptible gradations into anthracite in the eastern parts, in a manner analogous to that of the South Wales coal-field in our own country. In the western, or bituminous districts, the coals are associated with limestones containing *Spirifer Mosquensis*, towards the centre these calcareous beds tail out, and are replaced by beds of sandstone and shale, which become hardened and altered as the coal-seams become anthracitic.

On the whole it would appear from the copious details and sections contained in the work of Murchison and his companions, that the coal-fields of the Russian empire, certainly of enormous area, are in some parts highly productive, and if vigorously opened up are likely to become of great economic value. The whole coal-producing series is of earlier date than the true Coal-measures of England; the greater part of the beds of coal being contained in the Carboniferous Limestone series, as in the case of Scotland and Ireland.

Poland.—At the south-western extremity of Poland, and within a short distance of the confines of the Russian, Austrian, and Prussian States is situated a small but extremely productive coal-field. It contains three known coal-seams, the middle one of which is no less than 16 yards in thickness, and is probably the thickest bed of mineral fuel in Europe. It is worked from the outcrop in mines near the village of Dombrowa, and has the following composition:—

Carbon	50·38
Volatile matter	47·23
Ashes	2·39
	100·00

This coal-seam dips from the outcrop at an angle of from 12° to 32°.

The two remaining seams vary from 3 to 9 feet in thickness, and differ from the main seam in having a smaller per-centage of volatile matter.

The area of the coal-field is supposed to be about 16 square miles. The formation belongs to the true Carboniferous period, reposing on Silurian rocks, and dipping under Tertiary strata.*

CHAPTER II.

INDIA.

The areas and resources of the coal-fields of India are as yet imperfectly known, but are now undergoing

* For this account of the Coal-field of Poland, I am indebted to Captain A. Antipoff, of the Russian Engineers.

the investigation of the Government geological surveyors, who have already produced some valuable maps and memoirs. The Messrs. Blanford, in their "Report on the Talcheer Coal-field," have shown that there at one time existed a widely-extended tract of carbonaceous deposits, which have been subsequently dissevered by denudation into the coal-fields of Rampur and Upper Damoodah, and, still further to the east, that of Burdwan.*

In the north-west are the coal-fields of Palamow, Sirgooja, and probably a chain of small fields connecting these with a great carbonaceous district stated to exist north-west of Sumbulpur.

The so-called "Talcheer coal-field" has been shown by Messrs. Blanford to be entirely destitute of coal.† The sedimentary rocks of this coal-field are composed of three groups, each resting unconformably on that beneath it. The middle or Damoodah group is at least of not more recent age than the Permian, as it is overlaid by shales which have yielded a minute Estheria, and the cranium of a Labyrinthodontoid batrachian. This coal-field yields rich iron-ores, capable of producing highly tenacious iron.

Professor Oldham describes a small coal-field of Eocene Tertiary age, resting on Nummulitic limestone, in the Khasi hills, Eastern Bengal; and in the north-western part of the same presidency there are extensive

* This coal-field has been also described by the Rev. Messrs. Hislop and Hunter, English Missionaries. Journ. Geol. Soc., vol. xi.

† Memoirs of the Geol. Survey of India, vol. i. part 1.

tracts yielding coal and lignite.* Of these, the coal-formation of Cutch is the best known. It is of the Lower Oolitic period, and is overlaid by sandstone of the age of the Kelloway rock, containing *Ammonites Herveyi.* It would thus appear to be the Indian representative in time of the Brora coal-strata of Sutherlandshire, of the Oolitic coal of Yorkshire, and of Virginia in the United States.—(Lyell.)

As far as our knowledge extends it would appear that the coal-fields of our Indian empire are not highly productive, that the coal is frequently of an inferior quality, and that it has been formed at several periods, from the Carboniferous to the Tertiary inclusive. The extent of coal-bearing strata is, however, very large.

China.—What may be the extent of the coal-fields of China, we have no means of judging. At the same time we know of several places where the mineral is mined. One of these districts is near the city of E-u, in the prefecture of King Hua (lat. 29° 15′ N., long. 119° 46′ E.). The coal is here worked in pits from 300 to 500 feet in depth, and the mines are opened out into galleries branching off into the seams at successive stages in the descent.† The mineral is also worked in the cliffs of the Pe-Kiang river at Tingtih, by means of adits driven into the side of the hill at the outcrop of the coal-seams. And lastly, at a place five miles from the city of Whang-shih-Kang on the river Yang-tse-Kiang, an account of which is recorded by Mr. Oliphant.‡

* Mem. Geol. Survey of India, vol. i., part 2.

† Rev. R. H. Cobbold, Journ. Geol. Soc., vol. xii.

‡ "Lord Elgin's Mission to China and Japan," vol. ii., p. 389.

The working of coal in China dates probably from a very ancient period. Our earliest notice is by the celebrated traveller, Marco Polo, towards the close of the 13th century.

Malaysia and Japan.—That magnificent group of islands lying between the Indian and North Pacific Oceans, seems to be as rich in the mineral treasures of the past, as it is in the vegetable productions of the present. Besides gems, and metallic ores in abundance, including iron, which yields the unrivalled Japanese steel, several of these islands contain strata stored with coal. And when we regard the geographical position of these islands, lying on the confines of the Eastern hemisphere, and in the track of vessels trading between America and Asia, the economic value of these sources of fuel can scarcely be over-estimated. It was on this account that the American expedition to Japan kept steadily in view the establishment of depôts for coal on several points on the coast of that island for the supply of American steam-vessels.* With a similar object the Indian government have given attention to the supplies of coal known to exist in Borneo, and have been successful in inducing the chiefs to form depôts of coal on the coasts. It is also satisfactory to learn that the trials made both in New York, Calcutta, and in the steam-vessels themselves, of samples of coal from these islands are very favourably reported.

In Japan, coal-mines are worked in the districts of Kiusin and Nippon; and the testimony of Kæmpfer

* "American Expedition to Japan."

regarding its abundance is corroborated by that of the officers of the American expedition. The Islands of Formosa and Karapty, the latter of which is now appended to the Russian Empire, also contains this mineral in considerable quantity.*

In Borneo, the province of Labuan on the north-west coast abounds in coal; and several beds outcrop near the river Gooty at the north-east of the island. Mr. Bellot states that the mineral resembles the best cannel, and burns readily.† It also occurs in Pulo Cheremin, an island at the mouth of the Borneo river, where it is stated to form a naked surface stretching out to sea, and laid bare at ebb tides. The glistening aspect of the mineral washed by the saline waters, and glancing back the rays of a tropical sun is said to have suggested its name of "Mirror Island."

It is highly probable that deposits of coal are by no means confined to the above island, but that they are also distributed more or less extensively throughout most of the islands lying between the Continent and Australia.

AUSTRALIA.

The state of Victoria contains carbonaceous deposits, from which coal has already been extracted. The Government geologist, Mr. Selwyn, has been engaged for several years in developing the mineral resources of this highly-favoured colony. Mr. Selwyn states that if the mass of the coal-bearing strata

* Atkinson's "Travels in the Amoor."

† Mr. T. Bellot. Journ. Geol. Soc., vol. iv.

of Victoria be Oolitic (Jurassic), there are certainly others in the eastern districts of the colony which contain plants of the true *Carboniferous* type, while the beds themselves rest and pass downwards into calcareous rocks with fossils, which are nearly all Carboniferous or Devonian forms.* How remarkable, that both here and at our Antipodes, in Britain in the Northern, and Australia in the Southern hemisphere—countries now standing in the relation of parent and child—Nature should have been elaborating mineral fuel during the same eventful period of the Earth's bygone history!

Sydney.—Coal-bearing strata occupy a large portion of the district of Sydney, stretching along the coast from Port Stephen's southwards. The formation containing the mineral has been described by M. de Strzelecki, who gives the following section of a coal-pit near Newcastle, showing no less than 5 beds of coal.*

	Feet.
Conglomerate	23
Coal	3
Cherts, gritstones with flint pebbles	44
Coal	5
Grey clay and shale with impressions of *Sphenopteris lobifolia*, *Glossopteris Browniana*, &c.	43
Coal	5
Greenish sandstone	25
Coal	3
Greenish sandstone	50
Coal (deepest bed)	3
Total depth	204

M. de Strzelecki also describes coal-deposits in two

* "Geology of Victoria," Journ. Geol. Soc. London, vol. xvi. p. 145.

"basins," those of the South Esk and Jerusalem, in Tasmania. They appear to be of the same geological age as those of Sydney, and, perhaps, Victoria. That this is the true Carboniferous epoch of the European coal-fields seems to be placed beyond question by the occurrence of shells of the genera *Spirifer*, *Productus*, *Nucula*, and plants, such as those above-mentioned.

New Zealand.—This beautiful island is rich in coal and lignite, which will prove of great value for steam navigation. Mr. C. Forbes describes carbonaceous strata in Preservation Island, Massacre Bay, and Waikato. They all belong to the Tertiary period.*

AFRICA.

The researches of Livingstone have brought to light coal deposits on the banks of the Zambesi, described by Mr. Thornton, geologist to the expedition now in progress. Dr. Livingstone has rightly estimated the beneficial effect upon the future navigation of this great river, likely to be exerted by the existence of these "stones that burn," the term by which the natives designate this mineral.

The carbonaceous deposits which are known to exist to some extent along the Eastern districts of the Cape of Good Hope have not hitherto proved of much value.

* Journ. Geol. Soc., vol. ii.

CHAPTER III.

NORTH AMERICA.

British Possessions.

THE States of America not appertaining to the British Crown have retained possession of by far the greater portion of the coal-producing region of the North American continent. In Canada proper, there exists not a vestige of the coal-formation; and the coal-fields within the boundaries of the British Empire are confined to its outlying north-eastern districts, of Newfoundland, New Brunswick, and Nova Scotia, and the borders of the Rocky Mountains. These we proceed to describe.

NEWFOUNDLAND.

From the survey of Mr. Jukes, it appears that there are two small, and as far as known not highly productive, coal-fields in Newfoundland; one extending along the eastern shore of St. George's Bay some distance inland, and the other from Grand Pond to White Bay.*

The formation is similar to that of Nova Scotia, consisting of two members which pass into each other. The lower member consists of red sandstone, red and green marls, with gypsum; the upper, of dark shales, fireclays, sandstones, and conglomerate and coal. This last has been found in several places, marked on Mr. Jukes' map, the thickest bed being about three feet.

* "Geology of Newfoundland."

NEW BRUNSWICK AND NOVA SCOTIA.

The geological structure and mineral resources of this region have been very lucidly described by Dr. Dawson.* From the excellent geological map which accompanies his work, it would appear that nearly one half of these territories are composed of Carboniferous rocks; but of this less than a third contains productive Coal-measures.

The following is the general succession of the Carboniferous series:—

	Thickness.
1. *Upper Coal Series.*—Grey and red sandstones and shales, conglomerates, and a few thin beds of limestone and coal of no economic value	3,000 feet.
2. *Middle Coal Series.*—Grey and dark sandstones, and shales, &c., with valuable beds of coal and ironstone; beds of bituminous limestone, and numerous underclays with *Stigmaria*	4,000 „
3. *Lower Carboniferous or Gypsiferous Series.*—Reddish and grey sandstones and shales, overlying conglomerates; thick beds of limestone with marine shells, and of gypsum .. .. .. more than	6,000 „

Fossil Remains.

The fossils of the upper series are composed principally of plants, as *Calamites*, *Ferns*, and Coniferous wood.

In the middle series, representing the middle Coal-measures of England, remains of both the animal and

* "Acadian Geology."

vegetable kingdoms appear to be remarkably abundant, and are classed by Dr. Dawson as follows:—

Reptiles.—*Dendrerpeton Acadianum*, discovered by the author and Sir C. Lyell, within the upright trunk of a Sigillaria. *Baphetes planiceps* a large batrachian allied to Labyrinthodon; besides one or more species indicated by their tracks.

Fishes.—*Palæoniscus*, *Holoptychius*, *Megalichthys*, and several other undetermined genera.

Articulata.—*Cypris* or *Cytherina*, several species. *Spirorbis*, either imbedded or attached to plants.

Mollusca.—*Pupa vetusta*, the first example of a land shell ever found in the Carboniferous rocks. *Modiola*, *Anthracosia* (Unio), of two or more speeies.

A large number of plants of European genera, and many of European species.

The lower Carboniferous series, representing all the strata of England, from the Millstone Grit downwards, contaius, a reptile, discovered by Sir William Logan; fishes of the genera *Holoptychius*, and *Palæoniscus*. Of Annelides, *Spirorbis* and *Cytherina*; of crustaceans, a *Tribolite* or *Limulus*; besides a large series of mollusca, of the genera *Nautilus*, *Orthoceras*, *Conularia*, *Euomphalus*, *Natica*, *Terebratula*, *Spirifer*, *Productus*, *Cardiomorpha*, *Pecten*, *Avicula*, *Modiola*, *Isocardia*, *Cypricardia*: of Polyzoa, *Fenestella*, *&c.*, Crinoids, &c.; and a few plants.

CUMBERLAND COAL-FIELD.

This is by far the largest Carboniferous tract, covering an area, according to Professor Rogers, of 6,889 square miles.* It extends along the whole line of coast, and as far inland as the base of a range of mountains

* Geol. of Pensylvania," vol. ii.

which trend along the northern coast of the Bay of Fundy. Its southern limits are the Cobequid Hills. Unfortunately, the surveys of this great coal-field have not tended to raise our expectations of its economic importance, as the greater portion of it appears to be composed of the Lower and Upper Carboniferous series, both of which are destitute of valuable coal-beds.

If economically unimportant, it is far otherwise in a scientific point of view, as, along the coast of the Bay of Fundy, at South Joggins, it displays the finest natural section of the Coal-formation in the world. The whole series of this district attain a thickness of 14,570 feet, with 76 seams of coal. Of these, 4,515 feet are brought to light in the coast-section. The beds rise along the face of the cliffs, clean and fresh, to a height of 150 feet, at an angle of 19°; so that in proceeding along the coast from north to south, for a distance of about ten miles, we arrive at constantly newer beds, which at low tide may be traced out from the base of the cliff for a distance of 200 yards. Sir C. Lyell counted 19 seams of coal, and at least 10 forests of upright stems of Sigillaria, the longest of which was 25 feet, with a diameter of 4 feet where broken off; and they were found invariably based on the upper surfaces of the beds of coal.

In the Cumberland coal-field, the principal coal is the "Joggins Main Seam," consisting of two beds, 3½ and 1½ feet thick. There are also workable seams at Springhill, besides several places in New Brunswick, especially a remarkable pitch-like vein called the "Albert Mine," on the Petitcodiac River.

COAL-FIELDS OF COLCHESTER AND HANTS.

This district is separated from that of Cumberland by the Cobequid chain of hills, and has an area of about 200 square miles. It is principally valuable for its limestone and gypsum. The coal-seams appear to be all under 18 inches in thickness.

COAL-FIELD OF PICTOU.

This coal-field has an area of about 350 square miles, and is remarkable for containing two very thick beds of coal, the upper 37 feet, and the lower 22 feet in thickness, separated by 157 feet of strata. These seams have partings of inferior coal, and ironstone at intervals. The upper bed has been largely worked at the Albion mines; and though there of good quality, has been proved to deteriorate at a short distance both to the north and south of that locality. The range of the lower seam is not yet known.

COAL-FIELDS OF RICHMOND AND CAPE BRETON.

The combined areas of these fields may be estimated at 350 square miles. Several workable seams of coal have already been discovered, besides valuable deposits of limestone and gypsum. For our knowedge of the Sydney coal-field we are particularly indebted to Mr. R. Brown, who gives the following synopsis :—The productive measures cover an area of 250 square miles, with a thickness of about 10,000 feet of strata.* Of several very fine natural sections exposed to view along the coast,

* Journ. Geol. Soc., London, vol. ii. and vi.

the most interesting is that to the north-west of Sydney Harbour, extending a distance of 5000 yards, and exhibiting a vertical thickness of 1860 feet of strata. Of these, 34 are coal-seams, combining to produce 37 feet of coal. Four only are workable. The following is the general section of these coals:—

	Feet.	In.
Cranberry Head Top Seam	3	8
Strata	280	0
Lloyd's Cove Seam	5	0
Strata	730	0
Main Seam	6	9
Strata	450	0
Indian Cove Seam	4	8

Valuable coal-seams occur also at Lingan and Bridgport; one of which, 9 feet in thickness, yields a fine coke, and is esteemed as a gas-coal. Limestone and gypsum also abound: and on the whole, the mineral resources of Cape Breton county appear very promising.

In 1851, the quantity of coal raised at Sydney was 53,000 chaldrons.

Emigrants and settlers would do well to make themselves acquainted with the mineral resources of the districts in which they propose to settle; as they may procure a tract of land which may prove, from its mineral wealth, of benefit to themselves and their descendants.

CHAPTER IV.

STATES OF NORTH AMERICA.

The great hydrographical basin of the Mississippi and its tributaries, is underlaid throughout the greater part of its area by productive Coal-measures, with enough coal to supply the whole of that vast continent, were it as populous and as industrious as Britain, for a decade of centuries. This great Carboniferous formation spread originally in one continuous sheet over the whole of Central America, probably from the flanks of the Rocky Mountains to the shores of the North Atlantic, and from the Gulf of Mexico to Newfoundland; and though we are unable strictly to define the original margin and limits of this great coal-generating tract, yet there is reason to believe, as has been pointed out by Sir C. Lyell, that land existed at that period where now rolls the Atlantic, and that the British Islands were connected with America by a chain of islands, or a tract of land, over which the plants of the Carboniferous period migrated and spread themselves in dense forests. Such an hypothesis seems the most satisfactory explanation of the remarkable fact, that the Carboniferous vegetation of America is identical, at least generically, with that of Europe; which could not have been the case under any of the received theories of the distribution of plants and animals, if these regions had been separated by wide barriers of ocean.

Moreover in tracing the Carboniferous strata, from Texas and Missouri on the south-west to the Alleghany Mountains and Nova Scotia on the east and north, we find a progressive thickening of the sedimentary materials, such as sandstones and shales, which become both more abundant, and of coarser texture, as we approach the sea-board of the Eastern States. This points to the position of the old land, from which these materials were derived, as having lain somewhere in the North Atlantic; and combined with the evidence derived from the vegetation, becomes almost demonstrative of the axiom, that what was land is now sea.

The great tract of Coal-measures, which was, without doubt, originally connected throughout, has now become dissevered into five coal-fields, the areas of which are thus stated by Professor Rogers:*—

The Appalachian Basin.—Length, 875 miles; average breadth, 180; area	55,500 sq. miles.
The Illinois, Indiana, and Kentucky Basins.—Length, 370; breadth, 200; area	51,100 „ „
The Missouri and Arkansas Basins.—Length, 550: breadth, 200; area	73,913 „ „
The Michigan Basin.—Length, 160; breadth, 125; area	13,350 „ „
The Texas Basin.—Length, 160; area ..	3,000 „ „
Total area	196,863 „ „

Over the central and western districts, the strata lie regularly, and only slightly removed from the horizontal position; but on proceeding eastwards, and approaching

* "Geol. of Pennsylvania." The reader would do well to refer to the small but very beautiful map of M. Jules Marcou, in Peterman's "Mittheilungen," vol. vi., 1855.

the chain of the Alleghanies, they become bent; and ultimately folded and crumpled along lines parallel to the axis of the mountains. Corresponding with this folding of the beds, the coals lose their bituminous properties, and along the western flanks of the mountains occur only as anthracite. The close connection between the crumpling of the coal-seams, and the loss of the volatile constituents of the coal itself, is strongly marked; for in proportion as we recede from the axis of disturbance, the coal-seams become more bituminous.

The Alleghany Hills consist of a succession of parallel ridges, divided by narrow and deep valleys, corresponding to the folding of the strata. The axis is nearly parallel with the coast of the Atlantic, and reaches at Black Mountain an elevation of 6476 feet. The geological structure of this remarkable range leads to the conclusion, that it has been formed by the exertion of lateral pressure, acting along the Atlantic side, and forcing the strata towards the west, with a power to which geology affords few parallels. In consequence of the structure of the beds, and the subsequent partial denudation, these mountains contain several small trough-shaped coal-fields, in which the coal has become metamorphosed, and assumes a columnar structure, the axes of the columns being perpendicular to the planes of bedding. There are also springs of pitch and petroleum,*

* An account of the discovery and opening of one of these oil springs at the village of Cuba, in Alleghany county, appeared in the New York "Tribune" of 8th January, 1861. When a pipe had been driven down 25 feet, the oil ascended with such force as to fill a barrel in an hour. Sometimes it was mixed with water.

of great value; and others of brine, containing 10 per cent of common salt (chloride of sodium), and small quantities of iodine and bromine. Free carburetted hydrogen also bursts forth at the fountains of the country.*

The thickness of some of the coal-seams is in keeping with the vastness of the coal-fields. In consequence of the thinning away of the sedimentary materials westward, several seams are often brought into contact, and form one mass. In the Bear Mountains there has thus been formed a seam of 40 feet in thickness, which is described by Sir C. Lyell. It is anthracite, and is quarried from the outcrop into the hill. Sir Charles considers that the thickness of the original mass of vegetable matter, before condensation by pressure, and the discharge of its various gases, may have been from 200 to 300 feet!

The Coal-measures, as in England, rest upon a floor of Carboniferous Limestone, with, in some places, Millstone Grit intervening; the age of the coal-fields in both countries is therefore identical. The fossils of the Carboniferous Limestone are generically the same with those of Europe—such as *Spirifer*, *Orthis*, *Terebratula*, *Productus*, *Pentremites*, and *Retepora*.

The plants from the Coal-measures are *Lepidodendron elegans*, *Sigillaria Sillimani*, *Neuropteris cordata*, *N. Loshii*, *Pecopteris lonchitica*, *Calamites Cistii*, &c., of which all but the second occur in Europe.

* Professor Rogers. From a communication to the British Association, 1860.

The Jurassic Coal-field of Richmond, Virginia.

Some miles east of Richmond a small coal-field of 26 miles from north to south, and 12 in its greatest diameter, occupies a depression in the granitic rocks of that part of the country. This coal-field has been shown by Professor Rogers and Sir C. Lyell to be of an age contemporaneous with the Oolitic coal-field of Whitby in Yorkshire, and the plants *Equisetum columnare* and *Pecopteris Whitbyensis* are abundant in both places.

The Richmond Coal-field contains several beds of valuable coal, one of which is from 30 to 40 feet in thickness, highly bituminous, and equal to the best coal of Newcastle.

Other Coal-fields and Lignite Formations.

Coal-fields of smaller extent and uncertain age occur, according to M. Marcou, at the sources of the Rio Colorado, in the Utah territory, and on the shores of the Pacific Ocean north of Cape Blanco.*

In Vancouver Island, and on the opposite coast of America, there are extensive deposits of Tertiary and Cretaceous age, bearing beds of lignite and coal, which are extensively worked for the supply of the steamers navigating between Victoria and the Frazer River.†

Mr. Isbister describes extensive lignite deposits in the valley of the Mackenzie River, probably of the same geological age as those in Vancouver Island. These strata have been traced by Sir J. Richardson from the shores of the Arctic Sea, along the eastern base of the

* "Geologische Karte der Vereingten Staaten," in Peterman's "Mittheilungen," 1855.

† Mr. Bauerman, "Journ. Geol. Soc.," vol. xvi., p. 201.

Rocky Mountains as far south as lat. 52°. The beds of lignite attain a thickness of 9 feet, and are well shown where the Bear Island River flows into the Mackenzie.

Dr. J. Hector, who accompanied Captain J. Palliser's expedition in 1857-60, has determined the Geological age of the lignites of North-western America and Vancouver Island to be Cretaceous, though others of inferior quality and of Tertiary age also exist.

Coal and lignite occur on Jameson Land, Banks' Land, and Melville Island. In Albert Land, in lat. 78°, Sir E. Belcher found bituminous schists with coal, and apparently connected with these strata, limestones with *Productus* and *Spirifer*. We have, therefore, grounds for believing, from these monuments of the Carboniferous age, that our coal-vegetation extended into regions which are at present so inhospitable as almost to exclude the existence of vegetable life. How great and wide-spread the changes of climate, and how mysterious the cause!

Produce of the North American Coal-fields.

The quantity of coal raised in the American States in 1855, was 5,000,000 of tons.* If we suppose it has since increased at the rate of ten per cent. per annum, the quantity for 1860 would be 7,500,000, or say eight millions of tons. If to this we add two millions for the produce of the coal-fields in the British Possessions, we have a total for the whole of North America of ten millions of tons.

Now, taking the area of these coal-fields at 204,000

* Taylor's "Statistics of Coal," 2nd edit., Philadelphia.

square miles, and comparing it with that of the British coal-fields, 5431 square miles, we find that the former is 38 times larger than the latter. But the quantity of coal raised in America is only about one-eighth the quantity raised in Britain; and in order that the development of the coal-fields of the former country should equal that of the latter, America ought to raise 2704 millions of tons annually.

TRINIDAD.

This Island has long been celebrated for its lake of mineral pitch; but besides this, it contains beds of coal and lignite, likely to become of considerable economic importance. The very successful survey by Messrs. Wall and Sawkins, the Report of which has just been published,* puts us in possession of all that is at present known. The strata with which the beds of coal are associated belong to the Tertiary period, and are very widely distributed. In the middle of the island there is a thickness of 6 ft. 10 in. of workable coal, in two beds; and in the southern section, double that amount in three beds. The strata, consisting of shales, sands, and carbonaceous clays, which contain these coal-seams, reach a total thickness of about 2000 feet. They range across the island in parallel zones, and present interesting sections along the coast, very faithful details of which are presented by Mr. Wall. The asphalt is almost invariably disseminated in the newer Parian group, which con-

* "Report on the Geology of Trinidad," Mem. Geol. Survey, 1860, with maps and sections.

tains the beds of lignite and a large amount of vegetable matter. It is considered by Mr. Wall to be the result of chemical reaction, conducted under the ordinary temperature of the island, producing bituminous, in place of ordinary anthraciferous, substances. The bitumen thus developed is exuded at the surface; and where a natural hollow occurs forms a lake.

The same Tertiary formations, under the term "Newer Parian," have been traced by Mr. Wall on the neighbouring coast of the Continent, and are known to contain lignite and coal at Piaco on the Orinoco, and in the provinces of Barcelona and Coro. Mineral pitch is also found with these strata.*

It is proper to observe, that these Tertiary lignites are inferior in economic value to the coal of the true Carboniferous formations of Europe and North America; and so long as these latter are shipped in sufficient quantity into the West Indian Islands, the fossil fuel of Trinidad is not likely to be largely worked.†

BRAZIL.

It is very probable that the central parts of the South American continent will some day be found to contain coal and lignite in considerable quantity. For the present we are assured that a coal-field of upwards of 60 leagues in extent exists in the centre of Brazil, capable of affording a supply for hundreds of years.‡

* Mr. Wall, Journ. Geol. Soc., vol. xvi.

† In 1859, no less than 99,100 tons of coal were shipped into the British West Indies from Great Britain.

‡ "Quarterly Review," 1860.

PART IV.

CHAPTER I.

AN INQUIRY INTO THE PHYSICAL LIMIT TO DEEP COAL-MINING.

THE reader will have observed that I have confined my calculations of the resources of our coal-fields to that portion of them included within 4000 feet of the surface, notwithstanding there are hundreds of miles stored with coal at greater depths than this. It is therefore proper that I should explain the grounds on which I consider, not only that all the coal below 4000 feet must for ever remain beyond our reach, but that in confining myself to this limit, I may have even exceeded to some extent the available limit of depth.

There are two agencies in mining constantly acting with increasing energy as we descend vertically from the surface—temperature and pressure; and though at first sight the latter would appear likely to offer the greatest obstacles to deep mining, it will probably be found that in reality increase of temperature will prove the first insuperable barrier. Let us examine this subject further.

That the earth has once been a fluid mass, molten by heat, and has subsequently cooled down at the outer surface by radiation into space, is a proposition which is based partly on direct, and therefore incontestable, observations of temperatures in mines, artesian borings, and hot springs; and partly on theoretical considerations, which have occupied the attention of the highest intellects from Strabo down to our own times. With the direct evidences we are only here concerned; but perhaps the strongest testimony of an internal heated mass pervading the interior of the earth, at a depth not very great as compared with the earth's radius, is afforded by the phænomena of granitic, plutonic, and metamorphic rocks, and the outburst of hot springs, and volcanic fires.

The following are some of the most interesting experiments which have been recorded for determining the rate of increase of terrestrial temperature in various parts of Europe.

The first of these is the experiment at the Puits de Grenelle, near Paris, the particulars of which are stated by Arago and Humboldt.* The water ascends from the Greensand formation which outcrops at Lusigny, south-east of Paris. The depth of the well from the surface is 1903 English feet, and 1675 feet below the level of the sea. The temperature of the spring is 81·95 Fahr., and the rate of increase is 1° F. for every 58·9 English feet.

At Neu-Saltzwerk, in Westphalia, a boring was commenced at a height of 232 feet above the level of the sea, and it reached an absolute depth of 2285 feet. Its

* "Cosmos," Sabine's Trans., vol. iv., p. 35.—See also Mr. W. Hopkins' Essay in the Philosophical Transactions, vol. cxlvii. This eminent authority considers the increase of temperature at an average of 1° F. for every 60 feet, as having been satisfactorily established.

temperature is 91° 04′ Fahr., and as the mean annual temperature of the air at Neu-Saltzwerk is about 49° 28′ Fahr., we may infer an increase of temperature of 1° for 54·72 English feet, or 1° cent. for 92·4 Paris feet.

The boring of the well at Neu-Saltzwerk, as compared with that of Grenelle, has a greater absolute depth by 461 French, or 491 English feet, and a greater relative depth below the level of the sea of 354 French, or 377 English feet; and the temperature of its water is 5° 1 cent., or 9° 18′ Fahr. higher. The rate of increase of temperature in the shallower well at Paris is nearly 1-14 less rapid than in the deeper well at Neu-Saltzwerk. This observation is important, as it is sometimes supposed that the rate of increase diminishes in a constant ratio as the depth increases.

Near Geneva an artesian boring to a depth of 724 English feet, gave an increase of 1° Fahr. for every 55 feet. The locality is at an elevation of 1600 feet above the level of the sea.

At Mondorff, in the Grand Duchy of Luxemburg, an artesian boring, of great interest, from the number of formations through which it penetrated, gave a result of 1° Fahr. for every 57 feet. The details were as follows:—

	Metres.
Lias	54·11
Keuper (Red Marls, &c.)	206·02
Muschelkalk (Limestone)	142·17
Grès bigarré (Sandstone)	311·46
Old schistose rocks	16·24
Total	730·00

An extensive series of experiments carried on in the mines of Cornwall, by Mr. R. Were Fox,* has induced that gentleman to arrive at the conclusion that the increase of temperature progresses in a diminishing ratio, and Mr. R. Hunt adopts a similar view founded on observations in the same district. Difficult as it is to conceive, and far more to account for, such a result, which would appear to show, that as we approach the source of the heat, the heat itself decreases, yet it cannot be denied that the results obtained by these observers (if taken by themselves) seem to favour the conclusions at which they have arrived. The following is a synopsis of Mr. Fox's experiments:—

A temperature of 60° at 59 fathoms below the surface.
„ 70° at 132 „ „ „
„ 80° at 239 „ „ „

Being an increase of

10° at 59 fathoms deep, or 1° in 35·4 feet
of 10° at 73 „ deeper or 1° in 43·8 „
and of 10° at 114 „ still deeper, or 1° in 64·2 „

The deepest observations were taken in the Tresavean mine in 1837, at the following depths:—

262 fathoms	1,572 feet	82°·5
290 „	1,740 „	85°·3
Same depth in another lode		86°·3
„ in a third lode		92°·1
Mean temperature for 1,740 feet		87·9

Mr. Hunt has found the temperature as high as 100° at a depth of 320 fathoms in this mine.

Allowing due weight to opinions coming from these observers, I cannot accept as of universal application an hypothesis of the increase of temperature in a diminish-

* Report. British Association, vol. ix.

ing ratio. It does not appear to be in harmony with the results obtained on the Continent, where the increase of temperature in the deeper well of Neu-Saltzwerk, is 1-14 more rapid than in the shallower well of Grenelle. Nor can it be reconciled with the observations in Dukinfield Colliery (about to be given in detail), where the increase in the uppermost strata, down to 270 yards, is 1° for 88 feet, and in the lowest down to 685 yards, 1° for 65·6 feet.

Professor Phillips has made observations on the temperature at the Monkwearmouth Colliery, which have shown an increase of about 1° for every 60 feet.

The experiments lately carried out by Mr. Astley, during the progress of sinking the Dukinfield Colliery, are perhaps the most valuable of any hitherto undertaken in this country. Through the kindness of Mr. Fairbairn, of Manchester, I have been supplied with the whole of the details, which I here insert at length. The observations were conducted with great care. The thermometer was inserted in a dry bore-hole, and removed as far as possible from the influence of the air in the shaft, and left in its bed for a length of time, varying from half an hour to two hours. The results also carry with them more than usual importance, from the fact that they extend downwards to a depth of 2055 feet, with an additional observation made in the open workings, at 120 yards from the shaft, and at a depth of 2151 feet.*

* Mr. Fairbairn has kindly allowed me to make use of these experiments for publication, but they will probably soon appear from himself in a more extended form.

Thermometrical Observations in the Dukinfield Colliery, Cheshire, between 1848 *and* 1859.

Date.		Depth in Yards.	Temperature Fahr.	Description of Stratum.
1848.				
July	28th ..	5·6	51°	Red rock—no variation.
1849.				
	1st	231	57·7	Blue shale—wet
	12th	234·7	58	ditto dry hole
	16th	237	58	ditto ditto
July	14th	239	57·5	
„	16th	240	58	ditto ditto
„	27th	242	57·5	ditto ditto
August	9th	244	58	ditto ditto
„	25th	248	58	ditto water
„	27th	248	57·25	ditto ditto
„	31st	250	57·25	ditto ditto
Novem.	14th	252	58	
Decem.	6th	256·5	58	Blue shale—dry
„	15th	262·5	58·5	ditto do.
„	22nd	270	58	Bituminous shale—dry
1850.				
January	9th	279	58·5	Strong warrant earth
„	26th	286·5	59·12	Rock bands
February	11th	293	59·5	Coal roof
„	19th	300	59·87	Warrant earth
March	5th	309	59·87	Purple mottled shale
1851.				
June	9th	358	62·5	Warrant earth
August	14th	373	64	Tender blue shale
Novem.	7th	403	65	Coal roof
„	19th	419	65·37	Rock bands
1852.				
February	6th	433	66·5	Black shale
May	28th	446	67	Strong fire-clay
1857.				
February	28th	483·5	67·25	Sandstone—dry hole
March	7th	487	67·76	Shale
April	11th	501	68·5	Sandstone
May	6th	511·5	68·75	Blue shale
„	19th	521·5	69·38	Strong shale
June	9th	533	69·75	Warrant earth
„	22nd	539	69·88	Blue shale
„	27th	546	71·75	Coal and earth
July	18th	555	71·25	Grey sandstone

Thermometrical Observations, &c.—continued.

Date.		Depth in yards.	Temperature Fahr.	Description of Stratum.
1857.				
August	1st	563	72·25	Red rock (Sandstone)
"	15th	569	71·25	ditto wet hole
September	2nd	578	72·12	ditto ditto
"	19th	589	71·5	ditto ditto
October	3rd	597	72·25	Grey rock—dry hole
"	17th	608	72·25	Coal roof—wet hole
"	27th	613·5	72·25	Coal floor ditto
1858.				
March	22nd	621	72	Strong shale—dry
"	29th	627	71·5	Dark-blue shale
April	23rd	645·5	72·25	Shale—dry hole
May	1st	651	72·25	ditto ditto
"	19th	658	72·5	ditto ditto
June	9th	669	73·25	Bituminous shale—dry hole
"	19th	673	74·12	Grey rock
July	17th	683	75·25	Blue shale
"	21st	685	75·5	do. do.
1859.				
March	5th*	717	75·0	"Black Mine" Coal roof.

Note.—The irregularities observable in the table are always to be expected in such cases. They arise from several causes, such as difference of density, conducting power, and moisture in the strata. Sometimes the water percolated to the bulb, and slightly affected the results.

1. The first observation gives 51° as the invariable temperature throughout the year at a depth of 17 feet. Between 231 yards and 270 yards, the temperature was nearly uniform at 58·0 And the increase from the surface would be at the rate of 1° F. for 88 feet.

2. Between 270 and 309 yards, the increase was at the rate of 1° for 62·4 feet.

3. Between 309 and 419 yards, the increase was at the rate of 1° for 60 feet.

* In workings at 120 yards down engine incline from the shaft.

4. Between 419 and 613 yards, the increase was at the rate of 1° for 86·91 feet.

5. Between 613 and 685 yards, the increase was at the rate of 1° for 65·6 feet.

6. The last observation, taken in the mine itself, at 120 yards from the pit, is valuable, as showing that the temperature of the air does not greatly differ from that of the surrounding strata.

The result of the whole series of observations gives an increase of 1° for every 83·2 feet, which is a less rapid increase than that exhibited by the generality of experiments.

I have been favoured by Mr. Bryham with a series of interesting observations upon temperature made at Rose Bridge Colliery, near Wigan. I first give those relating to the temperature of the strata, made in sinking the shaft between the years 1854 and 1856, and reaching to a depth of 600 yards.

Thermometrical Observations at Rose Bridge Colliery.

Date.	Depth in Yards.	Temperature Fahr.	Description of Stratum.
1854.			
July	161	64·5	Blue shale
August ..	188	66	Warrant earth or fire-clay
1858.			
May	550	78	Blue shale with ironstone bands
July	600	80	Warrant earth
1861.			
March* ..	600	72	Two feet in solid strata at pit bottom

* The strata had been cooled down by exposure to the air-current.

It will be observed that these observations show a greater increase than those of Dukinfield, and more in accordance with those of other districts.

The Coal-formation may be expected to show greater irregularities than many other formations of a more uniform composition and density, consisting as it does of a great variety of strata alternating with each other, differing in porosity, conducting power, mineral character, and in the greater or less facilities for the percolation of water, we cannot expect a formation of this kind to exhibit everywhere a uniform increase of temperature in descending through it. Nevertheless, the above results justify us in assuming a more gradual increase than 1 degree for 60 feet, in the case of coal-mines; and if we adopt an amount of 1 degree for 70 feet, which is a mean value between the results obtained at Dukinfield colliery and other sources, we shall not, in all probability, greatly err.

In endeavouring, then, to ascertain what would be the temperature in coal-mines at a greater depth than 2000 feet, we must first determine the temperature to which the addition of 1 degree for 70 feet is to be made. This is shown by the first observation recorded in the above table—viz., 51 degrees, at 17 or 18 feet. In general it has been found that at a certain depth, varying from 15 to 50 feet, the temperature remains the same all the year round; and is nearly that of the mean annual temperature of the air. The depth of this "invariable stratum," according to Humboldt, depends upon the latitude of the place (increasing from the equator towards the poles), on the conducting power of the rock, and on the amount of difference between the temperatures of the hottest and coldest seasons. At Greenwich, the mean temperature, is 49·5°; and in the deepest of several underground thermometers, 25 feet from the surface, the extreme variations were (1858), from 48·85° to 52·27°, giving a mean of 50·56°—a result, differing by only half a degree from that of Dukinfield Colliery, obtained ten years earlier.*

We may therefore adopt 50·5° as the standard of departure—or in other words the *temperature of no variation* at a depth of 50 feet underground.

But there is an additional element tending to raise the heat in deep mines; namely, the increased density of the air. This is a constantly augmenting quantity, but may be taken, for general purposes, at 1 degree for every 300 feet of depth.

Combining these two elements, we obtain the maximum temperature at the various depths shown in the following table:—

Table showing the theoretical increase of Temperature at several depths; the "temperature of no variation" being taken at 50·5° Fahr., at a depth of 50 feet from the surface.

Depth in feet.	Increase of Temperature due to depth.	Increase of Temperature due to density of air.	Resulting Temperature.
1,500	21·42	5·0	76·92
2,000	27·85	6·5	84·85
2,500	35·5	8·5	94·00
3,000	42·14	9·83	102·47
3,500	49·28	11·66	111·44
4,000	56·42	13·16	120·08

* "Greenwich Observations" for 1858.

The above results give a more rapid increase than that offered by direct experiment at Dukinfield colliery; but will be found to correspond more closely with the observations at Rose Bridge Colliery, near Wigan.

That this increase of temperature is entirely independent of atmospheric agency, or the elevation of the place relatively to the level of the sea, is proved by the interesting experiments of Humboldt. In a silver mine above the little town of Micuipampa, situated on the Andes of Peru, at an elevation of 11,875 English feet above the sea, the great traveller found that the temperature of the Mina del Purgatorio, was 25·4° Fahr., higher than that of the external air. The mean annual temperature at Micuipampa is about 45·5° Fahr., the temperature at the bottom of the mine was 79·6°, being an increase of 34·1°.

In another mine at the same elevation, the difference between the internal and external air was 15·8° Fahr., and the waters which were streaming down showed 52·3° Fahr. Similar results were obtained in other localities,* leading to the conclusion that the source of heat is internal, and independent of the form of the ground or its elevation.

If we are justified, then, in concluding that the internal heat of the earth under our feet is such that at a depth of about 2500 feet, the mean temperature would reach upwards of 90°, equal to that of the tropics, it is evident that this depth becomes the ultimate limit to mining operations, unless we succeed in reducing the temperature by artificial appliances.

* "Cosmos." Sabine's Trans., vol. iv.

Ventilation is the great means to which we must look, not only for supplying pure air, but for keeping the mines sufficiently cool for mining purposes at great depths. It is not improbable that the constant flow of cooler air through the arteries of a mine, will have the result of ultimately lowering the temperature of the strata through which it passes. We should expect that its effect would be to carry away the supply of caloric given off from the heated surface of the rock, and thus eventually to reduce the temperature of the mine. Yet it would appear, from an observation recorded by Humboldt, that this permanent cooling of the rock, after several years of exposure to the atmospheric air is an exceedingly slow process. We all know how much hotter are the narrow, ill-ventilated parts of a mine, where a thorough draft has not yet been established, than the main passages through which the air constantly circulates. On this point, the experiments which have been kindly undertaken by my friend Mr. C. Wright, at Shireoak colliery, tend to throw some light. Premising that this colliery has been but recently opened, and that the workings are not at present very extensive, it was found, first, that the "intake air"* had a temperature of 63°; while the "return air" was 69°, or 6° higher—certainly a moderate increase of temperature; but, be it remembered, after a comparatively short circulation.

In a "goaf" or chamber, removed seven yards from the air current, the temperature was 72°; being an increase of 9° upon the "intake air."

* *i.e.* The air at the bottom of the shaft, before entering the passages.

Lastly, in a "close heading," 80 yards from the air-current, the temperature was found to be 86°, or no less than 23° higher than that of the intake air. It is not improbable that in this heading a certain amount of heat was generated by spontaneous combustion.

These results show the effect of a free current of air through the works in moderating the heat due to the causes above assigned.

The depth of Shireoak colliery is 510 yards, or 1530 feet. Now, according to the calculation given in the above table, the temperature ought to be 77·45°, which is about a mean between that in the "goaf," seven yards from the air-current, and that in the "close heading," 80 yards from it. Again the temperature of the "return air," which had passed through the workings, was 69°, or nearly 10° under that due to the depth. We may therefore conclude that the *general* effect of the ventilation would be to reduce the temperature by about 10° and upwards.

A valuable series of experiments have been kindly made for me by Mr. Bryham, in a still deeper colliery, that of Rose Bridge, near Wigan, already alluded to, in two coal-seams, the upper being the "Pendleton Four-feet," at 300 yards deep, and the lower the "Cannel Mine," at 600 yards. I give them in full.

I may here be allowed to suggest to managers and proprietors of deep collieries the advisability of adding to our knowledge by carefully conducted experiments to determine the effects of ventilation in moderating the temperature of mines during different seasons of the year. The observations ought to be made with good thermometers.

Observations on Temperatures of Air Currents, &c., at Rose Bridge Colliery, Wigan.

Temperature at surface in shade 56°.

Date.	Depth in Yards.	Air-current. Cubic ft. per min.	Temperature of intake air.	Temperature of return air.	Gain of heat.	Distance travelled by the current.
1860. Sept. 4th	300	35·00	59·5	64·0	4·5	1,000 yards.
"	..	..	..	68·0	8·5	4 yards out of air-current.
"	600	81·76	60·5	73·0	13·0	1,500 yards.
"	..	..	..	75·0	15·0	8 yds out of current.

Temperature at surface in shade, 42°.

Date.	Depth in Yards.	Air-current. Cubic ft. per min.	Temperature of intake air.	Temperature of return air.	Gain of heat.	Distance travelled by the current.
1861. Mar. 18th	600	105·58	50·75	..	..	Main intake.
"	..	96·40	..	68·75	18·0	Taken in Dumb Drift; distance travelled 2,200 yards.
"	..	23·26	51·5	67·5	16·0	Distance travelled 2,400 yards.
"	..	31·50	51·0	..	..	
"	..	21·00	..	71·0	20·0	Distance travelled 3,140 yards.
"	..	10·50	..	67·5	16·5	Distance travelled 1,900 yards.
"	..	..	60·0	..	..	4 yards out of main intake air.
"	..	..	..	71·75	11·75	4 yards out of main return air.

Barometer in Cannel Mine (600 yards) 30·5, at surface 28·8.

The above experiments show many points of interest.

1. We cannot but be struck with the enormous amount

of caloric continually being carried off from the mine. Thus in one of the experiments it is shown that at a depth of 600 yards, a current of air equal to 21 cubic feet per minute, passes off from the mine 20° warmer than it entered, after circulating through 3140 yards. 2. It will be observed that the surface temperature, depending upon the season of the year, materially affects the temperature of the whole mine; and if the extreme temperatures of summer and winter had been observed, the results would doubtless have been proportionate. Thus with a surface temperature of 56°, the return air is 73° with 1500 yards of circulation, while with a surface temperature of 42°, the return air is only 67·5° with 1900 yards. 3. The increase of heat received by the air while passing down the shaft appears to be considerable. Thus in a depth of 300 yards the increase was 59·5 — 56 = 3·5°, and in a depth of 600 yards the increase was 60·5 — 56 = 4·5° in September, and 50·75 — 42 = 8·75 in March. Lastly: Several observations show how necessary is the air-current in moderating the temperature, for whenever the thermometer was placed beyond its influence, the mercury immediately ascended. All these points bear directly upon the question of deep mining.

We must also take into consideration the effect of the ventilation at different seasons of the year. This is considerable. I have known water at the bottom of a deep pit to have been frozen several inches during the prevalence of severe frosts. Therefore, if the current-air should descend the shaft, and enter the works at a temperature of from 30° to 40°, there is every probability that it would be able to reduce the heat even of a mine 4000 feet in depth, to a degree not only tolerable, but admitting of healthy labour.

I therefore look forward to the possibility of mines being carried down to such a depth, that it will be practicable to excavate the coal during the winter months only.

Pressure.—It is impossible to speak with certainty of the effect of the accumulative weight of 3000, or 4000 feet of strata on mining operations. In all probability, one effect would be to increase the density of the coal itself, and of its accompanying strata, and so to increase the difficulty of excavating. Coal-mining labours under a disadvantage not felt in mining other minerals, namely, the impossibility in general of having recourse to blasting. The increased firmness of the strata will most assuredly be felt; but the question whether its resistance will prove beyond the powers of manual skill and mechanical contrivances to surmount, can only be solved by actual experience. I am informed by Mr. Bryham, that from his experience the density of coal-seams is not perceptibly greater at 500, or 600 yards, than at half that depth.

In the face of these two obstacles—temperature and pressure, ever increasing with the depth—I have considered it utopian to include in calculations having reference to coal-supply, any quantity, however considerable, which lies at a greater depth than 4000 feet. Beyond that depth, I do not believe it will be found practicable to penetrate. Nature rises up and presents insurmountable barriers.

Recapitulation.

The results at which we have arrived are briefly as follows :—

1. There are coal-deposits in various parts of Great Britain, at all depths, down to 10,000 or 12,000 feet.
2. That mining is possible to a depth of 4000 feet, but beyond this the high temperature is likely to prove a barrier.
3. The temperature of a coal-mine at a depth of 4000 feet will probably be found as high as 120° Fahr.; but there is reason to believe, that by the agency of an efficient system of ventilation, this temperature may be so reduced, at least during the cooler months of the year, as to allow of mining operations without unusual danger to health.
4. That for working mines of greater depth than 2000 or 2500 feet, underground stages, with independent winding machinery and engines, will be found not only to render very deep mining practicable, but also to lessen the amount of risk from accident.
5. Lastly. Adopting a depth of 4000 feet as the limit to deep mining, there is still a quantity of coal in store in Great Britain, sufficient to afford the present supply for a thousand years.*

* See p. 236.—The quantity of coal in England and Wales would only afford the *present* supply of 72 millions for 1000 years; but, with the Scottish Coal-fields included, the amount will allow of the increase above stated.

CHAPTER II.

DURATION OF OUR COAL-SUPPLY.

THE results we have arrived at are from their nature definite and determinable. Though only approximately correct—perhaps rather overstating the coal-supply than the contrary, yet it is reassuring to know that there is an available quantity of coal of 79,843 millions of tons, which, if divided by 72 millons of tons (the quantity raised in the year 1859 nearly), would last for no less than 1100 years.

Yet we have no right to assume that such will be the actual duration; for the history of coal-mining during the last half century has been one of rapid advance. The actual amount of this increase is rather uncertain, owing to the fact that, until the collection of the mineral statistics by Mr. R. Hunt, of the Mining Record office, we had no returns upon which much dependence could be placed.

According to Mr. M'Culloch, the quantity of coal raised in 1840 was 30 millions of tons; and taking the quantity raised in 1860 at 72 millions, it would appear that the produce had more than doubled itself in twenty years. Supposing that Mr. M'Culloch's estimate is rather below the truth, we shall assume that, in the twenty years ending 1860, the supply exactly doubled itself. Now if we had reason to expect that the increase of future years was to progress in the same ratio, we might well tremble for the result; for that would be nothing less than the utter exhaustion of our coal-fields, with its concomitant influence upon our population, our commerce, and national prosperity, in the short period of 172 years!

The following calculation brings us to this result.—The produce in the year—

				Millions of tons.	
1860	was	..	..	72	Total supply, = 79,843 Millions of tons.
—80	would be	..	..	144	
1900	..	..	..	288	
—20	..	..	..	576	
—40	..	..	..	1,152	
—60	..	..	..	2,304	
—80	..	..	..	4,608	
2000	..	..	..	9,216	
—20	..	..	..	18,432	
—33-34	..	..	..	42,979	

That is to say—the total available supply would be exhausted before the lapse of the year 2034.*

But are we really to expect so rapid a drain in future years?—I think not; and for the following reasons.

In the first place, we may expect that America will come to our aid in assisting to supply the world with coal. As I have already shown, the supply from that great reservoir has hitherto been extremely limited; and as appears by the returns, Britain actually exported 201,436 tons during the year 1859, to the United States.

* It is scarcely necessary to observe that the exhaustion of our coal-fields could never in any case take place *abruptly*. The supply must reach a maximum, and afterwards gradually decline.

She has also largely shipped her coal into almost every port in the Old and New World, including those of Brazil, West Indies, and the British Colonial Possessions —countries whose rocks are more or less richly stored with this very commodity. We need not dwell upon her exports to other parts of the world, collected and tabulated with admirable industry by Mr. Hunt.* In glancing over the long catalogue of names, we scarcely miss a single territory of note in any part of the globe. But such an outflow of the life-blood of this country cannot long continue, while on the opposite shore of the Atlantic there lie in their pristine integrity coal-bearing tracts upwards of *seventy times* the area of our own. According to all the laws of commerce, the steady rise in the price of coal in this country, enhanced by shipment to far distant ports, must call into existence the dormant energies of our neighbours who, by a moderate amount of mining enterprise, are well capable of at least relieving us of the privilege of supplying the New World with mineral fuel.

Another reason for not anticipating an increase as rapid as that of the preceding quarter of a century is, that there has until lately been a great, and in some cases culpable waste, both in the getting and using of the mineral. This arose from a variety of causes—imperfect modes of mining, and the impossibility of obtaining a market for any but the finest qualities of whole, or unbroken coal. At present very little of a good coal-seam is left behind in the mines; and the

* Mineral Statistics, 1859.

small coal, or slack, which used formerly to be left behind, or else destroyed, is now raised and sold at a cheaper rate than the block coal.

Greater economy is also being effected in the use of the precious mineral. Owing to its high price, even in the mining districts themselves, manufacturers are substituting for the old wasteful boilers, others, for which an equal amount of steam can be generated at the expense of one-third of the fuel previously used. Thus the increased price of coal is producing the salutary effect of husbanding the supply; and we cannot but feel that it is a crime to waste a single ton.

On the other hand, there are constantly in operation certain causes, natural, political, and commercial, tending to accelerate the drain. The first of these is the increase of population in our own country: and Mr. Hunt informs me, as the result of his experience, that for every additional person born there is required an additional ton of coal. Now, during the last fifty years the population of Great Britain has increased nearly nine millions; and though we can scarcely expect an increase in the same ratio, owing to the greater impetus which emigration has received lately, yet, until those compensatory influences which are in constant operation, shall bring about an equilibrium between the capacity of the land and the number of its inhabitants—a very distant prospect,—we have here a most certain cause of an increased drain on our coal supply. We may however reasonably expect that the advance of science will enable us materially to economise fuel, even for domestic purposes; but even on this supposition, we must allow an increase of one million of tons for every five years, for increase of population alone.*

The next great cause, or rather system of influences, likely to accelerate the drain of our coal, is the increase of our manufactures—at present very rapid—and the gradual substitution, to a large extent, of steam-vessels for ships in our navy and mercantile marine. It requires no gift of prophecy to foresee to how great an extent this is likely to proceed; and in the next half century, the sail may be of the two the rarer means of propulsion. In this, however, lies our safety. I can conceive the coal-fields of this country so far exhausted, that the daughter in her maturity shall be able to pay back to the mother more than she herself received. May we not look forward to a time when those "water-lanes" which both dissever and unite the Old and New World, shall be trod by keels laden with the coal-produce of America, for the ports of Britain? and in such a traffic, there will be abundant use for vessels as capacious and swift as the "Great Eastern."

The third and last cause which I shall notice is the export to Continental countries. At present this amounts to about 4½ millions of tons;† an amount likely to in-

* As the population increases in an accelerated ratio, a proportionate increase in the coal supply would also be necessary; but for our purpose the above is sufficiently near for the next half century.

† 4,316,136 tons in 1859.

crease, owing to the repeal of the protective duty. I think it will scarcely be denied, that Parliament granted an unwilling assent to a measure which gave an unlimited freedom to the drainage of our resources in the special article of coal. That measure was carried chiefly, though not altogether, in deference to the great principle of free-trade; but even the most ardent advocates of free commercial intercourse cannot but be aware that the doctrine may not be applicable to a mineral which, when once consumed, cannot be reproduced. That we shall ultimately return to the principle of retaining for our own use that mineral upon which the wealth, commerce, and political influence of this country so largely depends, can only be a question of time.

It may possibly arise, however, that the vertical limit of mining shall be ultimately regulated more according to the laws of commerce, than from the influence of physical obstacles. Even before reaching those depths where either the temperature of the mines, or the increased density of the mineral, may render mining impracticable, other countries may come into the market, and be able to supply Britain with fuel at a cheaper rate than she can supply herself. The deeper the mines, the larger the outlay in the first instance, and the greater the expense of mining ever after; and these expenses increase in a more rapid ratio than the depth. Thus, if it cost 100,000*l.* to open a colliery at a depth of 2000 feet, it would probably require 250,000*l.* to open one at twice that depth. The value of the coal must therefore increase in a proportionate rate with the outlay; and it may therefore one day so happen, that the price of coal in Britain shall reach such a point, that other countries may step in and undersell our own colliery-proprietors. Now, if ever such a state of affairs arrives (and judging by the analogy of the past, not always a safe guide, such a course of events appears certain), the only country likely to enter into the market is America. Can we not see in this another impulse to the westward march of civilization? And may not the incubus of slavery find relief by the diversion of the industry of those large tracts, now constituting the Slave States, into new channels? The factories of Britain, supplied with the raw material from her Indian Empire on the one hand, are fed by the coal-fields of America on the other. Thus placed as she is in a central position, accessible on every hand by sea, and supplied with machinery, she still remains the great workshop of the world. Like the heart which gives back, renewed and fitted for its functions, the blood it receives crude and impure, and thus imparts energy and life to the whole frame, so Britain, the world's great heart, may be destined to play a similarly important part in that world's future life. America possesses, in her great rivers, noble highways for pouring forth into the broad ocean the riches of her coal-fields, even independently of artificial means of transport; the progress of steam-navigation leads us to expect that not long hence the average time for crossing the Atlantic will be seven days; and it therefore requires no prophetic powers to foresee the accomplishment of Captain Maury's fine thought—of the formation of real, though invisible, water-lanes through the *dissociabilis æquor* connecting Britain and America, along which, to avoid catastrophe, it will be as necessary for steam-vessels to steer their course, as for trains running in opposite directions on the same railway, to keep to different lines of rails.

How far these speculations shall have their fulfilment, time only can show. We are short-sighted creatures at best; and God is as merciful as He is wise, in denying to us the power of looking far into the future. It cannot, however, be otherwise than assuring to know, that even such an event as the exhaustion of our own coal-supply, however far or near in time, will not necessarily be attended with the utter collapse of our national industry; because America is ready, when the time arrives, to stretch forth the helping hand.

The coal-fields of Russia are also of large extent; and though but very partially developed, or even explored, may yet be destined to play a large part in the commerce of Europe.

Meanwhile science, and especially chemistry, we may feel sure, will not be slow in eliminating for our use the light and heat that is everywhere around us. The researches of Dr. Joule have shown that these agents are only a kind of motion—or rather the results of motion in matter; and *that* matter we have in water, in air, and in a thousand embodied forms; nor can we suppose that any part of the Creator's universe has been regulated on so short-sighted a plan, that it shall become disorganized because some of the elements necessary to its economy have failed.

Leaving these speculations, let us look at the subject from a practical point of view. I have already stated my reasons for believing that the increase of production, reckoned from the earlier part of the present century, is not to be considered as an index to that of future years. The estimates for those years are little more than guesses; and the expansion of commerce during them was exceptional. I prefer taking as an index the increase for the last five years, which, as I have shown, amounts to about 1½ million of tons per annum, or 150 millions in a century. At this rate of increase, let us examine for what length of time the available supply, to a depth of 4000 feet, would be likely to last.

Taking the total available quantity of coal in Great Britain at 79,843 millions of tons, it will be seen by the following table that, with the above rate of increase, it would be only sufficient for upwards of 300 years.

Produce in the years—

	Millions of tons.	
1860	72	
1860 — 1900	2,940	Total supply.
1900 — 2000	13,350	= 79,843
2000 — 2100	28,350	Millions of tons.
2100 — 2185	35,131	

The reader will, however, concur with me in the opinion that prognostications extending to three centuries are as useless as they are likely to prove erroneous. We need scarcely trouble ourselves with the destiny of the race of the fifth or sixth generation. The production of coal can never in any case reach a maximum and then suddenly collapse; and it is very doubtful if the circumstances of the coal-fields would admit of a much greater drain in any one year than one hundred millions of tons, or 10,000 millions in a century. In this case the supply is sufficient for eight centuries.

In the first edition of this work, it was stated that there was sufficient coal in England and Wales to last, at the present rate of production, or 60 million of tons, for a thousand years. The calculation here given includes Scotland: and we find that in the whole of Great Britain the supply is sufficient to last for *upwards of* a thousand years, with a production of 72 millions of tons annually. It thus appears that the drain on the Scottish coal-fields, in proportion to their powers of production, is far less than on those of England and Wales in proportion to theirs. Nor have the resources of Scotland been exaggerated; as it will be observed that my estimate is greatly below that of previous authorities.

CHAPTER III.

THE PHYSICAL GEOGRAPHY OF THE CARBONIFEROUS PERIOD OF BRITAIN.

There is an economic interest attaching to this subject which rarely falls to the lot of geological speculations. It involves the question of the extent to which the Coal-formation may be inferred to underlie the south-eastern parts of England, where it dips under, and is for ever concealed beneath the newer formations. We have to inquire whether the whole extent of country in the direction of the Thames and the Channel was so far depressed during the coal-period as to admit of the growth of vegetation and the deposition of strata, or, on the other hand, retained the character of a mountainous tract of dry land. It then remains for inquiry how much of the coal formed over a portion of this tract was subsequently removed by denudation of the old seas.

Land Surface of Central England.—Mr. Jukes was the first to show, what is now generally admitted upon stratigraphical grounds,* that during the deposition of all the older, and the greater portion of the newer Carboniferous strata, including the Coal-measures, a tract of land stretched right across the centre of England, from Hereford and Salop, in the direction of the Wash. This tract formed a barrier between the coal-fields of the northern and central counties, and those of South Wales, Somersetshire, and the Forest of Dean. In a westerly direction, it comprehended probably the greatest part of the North Welsh Highlands, and those parts of Shropshire which include the Longmynd and neighbouring ranges. The boundaries of this land towards the north were doubtless irregular, and we may suppose it to have been varied by bays and headlands. One of these headlands probably protruded northwards, along the western side of the Coalbrook Dale coal-field.† Within the bays, the coal-fields of the Clee Hills, and the southern extremities of those of the Forest of Wyre and Warwickshire were probably formed. Nor can it be doubted that the thinning away of the strata, the deterioration of the coal-seams, and the absence of the lower portions of the

* Memoir on the South Staffordshire Coal-field, 2nd edit.

† About 1½ mile north of Wellington, in a boring beneath the New Red Sandstone, trap was found.

Coal-measures at the southern extremities of the four coal-tracts of the central counties, indicate the proximity of land.* The old Cambrian rocks of Charnwood Forest, though once *partially* covered by coal-strata, and the bosses of trap which project through the Red Marl, east of Atherstone, help us to trace the margin of the old coast. Its further course we can only attempt to define upon theoretical considerations to have been towards the north-east, entering the sea somewhere between the Humber and the Wash, and stretching in the direction of the Scandinavian promontory.

The southern margin of this land-surface is even more difficult to define than the northern, and it is, therefore, impossible for us to determine with any degree of certainty, whether any part of that large tract lying between the valley of the Thames, and the coal-fields of the central counties is underlaid by productive Coal-measures. The Oolitic and Lower Cretaceous strata along the Thames valley, near Farringdon and Abingdon, as shown by Mr. Godwin-Austen, afford indications of the proximity of ancient palæozoic† rocks. The Portland Limestone and the Lower Greensand are filled with pebbles, in the latter of large size, composed

* Mr. Jukes states that deep borings at the southern extremity of the South Staffordshire coal-field have proved the absence of those lower measures which, further north, are so rich in ironstone. (*Iron Ores of Great Britain.*) A bank of Silurian rocks is also known to stretch for some distance along the east side of this coal-field, which cuts out the coal-measures, as proved at Lord Dartmouth's colliery. South-east of Rowley, the main coal becomes so split by sandstone, and thins out so rapidly, as frequently to be not worth working.

† *i. e.* Silurian or Cambrian.

of Lydian stone, quartz rock, and slate. Whatever the age of the rocks from which these pebbles have been drifted, they are certainly older than the Carboniferous; but they may have been upheaved and laid bare after the Carboniferous epoch.

Again, at Harwich,* slate-rock apparently cleaved, and in all probability older than the Carboniferous period, has been proved by boring beneath the Tertiary strata.

The deep artesian boring at Kentish Town is very instructive. At a depth of 1122 feet from the surface, and underneath the Gault, a conglomerate bed was discovered, and Mr. Prestwich,† who closely watched the progress of the work, states that this conglomerate yielded specimens of various old and crystalline rocks, as syenite, greenstone, porphyry, quartz, and granular schist, with traces of fossils; all evidently of a pre-Carboniferous age. Underneath these were found beds of reddish sandstones and marl of uncertain age. It is much to be wished the boring had been carried a few yards further down.

It would, therefore, appear, from the evidence of these conglomerates of various ages, that they are in the neighbourhood of very old crystalline and schistose rocks, though it is impossible to say how far the pebbles may have travelled. On the other hand, the evidence of the extension of the coal-formation into the counties immediately north of the Thames is absolutely nothing.

* Jour. Geol. Society, vol. xiv. Mr. Prestwich, Sir C. Lyell, and Mr. Bristow, have all stated to myself their opinion that these slate specimens are of an earlier date than the Carboniferous. Appendix H.

District South of the Thames.—It has been seen that the coal-fields of Belgium and France stretch in the form of a deep trough from Liege towards Boulogne. Here we lose all trace of the Carboniferous rocks till we reach Somersetshire, where we find the axis of upheaval along the range of the Mendip Hills, directly in line with, and corresponding to that of the Carboniferous strata of France, known as the axis of Artois. Hence it has been suggested by Mr. Godwin-Austen* that the one may be a prolongation of the other, under the Cretaceous and Wealden groups, south of the valley of the Thames. In accordance with this theory, we might expect a band of Coal-measures, continuous with that of Somersetshire, to stretch under Salisbury Plain, or the Vale of Wardour, and right across the country towards Dover; and that some such *general* arrangement of the strata actually exists is highly probable. It is not, however, generally known that at its southern extremity the Somersetshire coal-field is actually a basin, and that the lowest beds of the Coal-measures rise to the east and terminate under the Lias and Oolite, before reaching Frome, Bradford, and Bath. This fact, proved, as I am assured by my friend Mr. Etheridge, by several borings and pits, may well lead us to be cautious in speculating on the existence of coal along the supposed axis of the Thames Valley. The uprising of the Lower Carboniferous rocks, west of Bradford, may be, and probably is, merely a local irregularity. It is in consequence of a line of dislocation which, ranging

* Journ. Geol. Soc., vol. xi.

along the Malvern Hills, produces the upheaval of the coal-field by Chipping Sodbury and Cleeve Bridge, near Dointon, and twists round the limestone of the Mendip Hills, from the east to the north-east and north.* Notwithstanding such an interruption, there is every probability that the Coal-formation again rolls in further to the east, in the form of a trough, as already explained; but the possibility of similar upheavals of the older rocks, renders it impossible to speculate with precision upon a subject of so much economic, as well as theoretical, interest.†

The North-westerly Drift of the Coal-measures.—It is a most interesting fact, that the strata which compose the Coal-measures thin away towards the south-east of England, and expand in volume towards the north-west. I have elsewhere shown that this is also true in the case of the Triassic, Liassic, and some members of the Oolitic formations.‡ The same principle has been shown by Professor Phillips § to hold good in the case of some of the Carboniferous series of Yorkshire, and by Mr. Geikie in the case of the coal-series of Scotland, where the sandstones and shales show a marked tendency to become thicker towards the north-west. These phenomena all point to the conclusion that, during the Carboniferous and subsequent periods, a continent or large tract o

* See ante, p. 79.

† In the map, I have indicated the possible extension of this band of coal-bearing strata by faint shading.

‡ "On the south-easterly attenuation of the lower Secondary formations," &c. Journ. Geol. Soc., vol. xvi.

§ "Geology of Yorkshire," p. 176.

land occupied the North Atlantic, and was drained by rivers, and swept by currents, which poured the sedimentary matter composing these rocks over the submerged portions of Britain.

I shall now give, as shortly as possible, the principal points in evidence of this *south-easterly* attenuation.

1. If we compare the Carboniferous series of Scotland with the corresponding strata in the north of England, we shall find that, in the former country, the sedimentary materials predominate enormously over those in the latter.

2. If we compare the Coal-measures (above the millstone grit) of Lancashire, with those of North Staffordshire, and this with South Staffordshire, we shall find a gradual lessening in the development of the strata from the north to the south. Thus :—

Thickness of Coal-measures in feet.

Lancashire.	North Staffordshire.	South Staffordshire.
6,800	5,000	1,810

The difference would appear still more striking if we had included the Lower Carboniferous series.

3. Again, if we compare the same sets of strata in Lancashire and South Derbyshire, or Leicestershire, we shall find the same fact borne out; thus :—

	Lancashire.	South Derbyshire.	Leicestershire.
Coal-measures	6,800	3,500	2,500
Millstone Grit and Yoredale Series.	5,500	600	75
	12,300	4,100	2,575

From the above sections, on the accuracy of which the utmost reliance may be placed, it will be observed how rapidly the sedimentary materials decrease in volume towards the south-east; and we might therefore be justified in concluding that, had the form of the old sea-bed admitted of it, the Carboniferous rocks would have ultimately died out towards the escarpment of the Chalk from failure of sediment. This was probably prevented by the barrier of land which, as we have reason to believe, stretched across the region now occupied by the Lias, Oolite, and Chalk.

Of the conclusions, then, we have arrived at, this is the sum. 1. The Midland and Northern coal-fields were separated from those of South Wales, Gloucester, and Somerset, by a tract of land of old Silurian or Cambrian rocks, the southern limits of which it is not possible to define with accuracy; but it is probable that it included the greater part of the district north of the Thames.

2. To the south of this tract of land lies another, but contemporaneous, system of Carboniferous rocks, extending, with many interruptions, from the county of Pembroke, through those of Glamorgan, Somerset, Wilts, Surrey, Kent, and across the north of France into Belgium.

3. The Carboniferous rocks of the central and northern counties, as well as those of Scotland, experience a rapid increase in thickness towards the north-west. The same law holds good also in regard to the lower Secondary formations, and leads us to infer the existence, throughout these periods, of a great tract of land,

lying in the direction of the North Atlantic, of which the Scottish Highlands may have formed part.

From the waste and denudation of this great Atlantic Continent, were derived the materials of which the Carboniferous and newer formations were built up; and if we could restore these formations to their pristine dimensions, and measure their volume, we should then be able to tell how great was the amount of waste this old continent experienced; and we might roughly estimate the period of its duration. The Highlands of Cumberland and Wales were also elevated for the most part during the same lapse of time.

The details on the map have been drawn in accordance with the above conclusions, and will enable the reader to discover whether any particular district is underlaid by the coal-formation, and if so, at what depth from the surface.

CHAPTER IV.

COINCIDENCES IN ENGLISH GEOLOGY.

There are certain coincidences in the history of the coal-period, in the characters of the strata which enfold the mineral itself, and in the present distribution of the carboniferous rocks relatively to those of more recent formation, which ought not to be left unnoticed in a work treating of the British coal-fields. The combination, in the same system of strata, of coal, iron, and lime has long since been used by Dr. Buckland and subsequent writers as evidence that the strata have not been allowed to accumulate altogether without an ordained plan. But whatever weight may be allowed to an argument for the wisdom and goodness of the Creator drawn from these sources (and on this point there will always be much diversity of opinion), it derives additional force from a consideration of the stratigraphical arrangement of the rocks themselves. Whether it proves anything or not, the subject is at least of sufficient theoretical interest to claim our consideration for a few moments.*

It has already been shown that the Coal-measures of England thin away and ultimately die out towards the south-eastern counties, and also that most of the region lying between Staffordshire, Warwickshire, and Leicestershire on the one hand, and the valley of the Thames and Channel on the other was dry land during the period of the productive Coal-measures, and *is therefore destitute of coal.* So that if this district, stretching eastward to the sea, and southward to the Thames, were stript of its covering of Cretaceous, Jurassic, and Triassic rocks, we should in all probability find a bare tract of Cambro-Silurian slates and porphyries.

Now when we cast our eyes over a geological map of England, the feature which most forcibly arrests our

* The reader will be assisted in understanding this subject by referring to the Map which accompanies the volume.

attention is the manner in which the formations are disposed. We observe them to stretch diagonally across the island in successive bands, outcropping towards the north-west, and dipping under each other in the opposite direction, so that if we make a traverse, for instance, along the line of the London and North-Western Railway, we pass in succesi on all the formations from the Tertiary to the Carboniferous between London and Dudley. Now, all this is owing to the strata having been upheaved towards the north-west, and a vast portion of them having been carried away by marine denudation; * for had they been left undisturbed and in their original horizontal positions, the older formations, including the Coal-measures, would have remained buried beneath the newer at great depths.

Again: a comparison of a number of sections made during the progress of the Geological Survey, have led me to the conclusion that those formations which overlie the Coal-measures, including the Permian, New Red Sandstone, and Lias, have a tendency to thin out towards the south-east (as is also the case with the Coal-measures themselves), and on the other hand, to become most fully devoloped in the direction of the Irish Sea between Wales and Westmoreland. This will be rendered clear by the following comparative sections, founded on actual admeasurements, between the north-west and south-east of the midland counties.

* When land is placed either during elevation or subsidence within the action of the waves, it is liable to destruction from their attacks, whilo the tide or other currents carry away the materials to other parts of the occan.

		Cheshire and Lancashire, N. W.	Staffordshire, Midland.	Warwickshire, S.E.
New Red Sandstone or Trias.	Keuper series	3,450 ft.	1,200 ft.	600 ft.
	Bunter "	2,150 "	800 "	absent.
		5,600 "	2,000 "	600 ft.

Here it will be observed that the attenuation of the Trias is so rapid, as to lead us to infer that in its prolongation southward and eastward from Warwickshire it scarcely extends below the Chalk of Cambridge or Bedfordshire.

In order to extend this comparison of developement to the Lias, I shall now give the following comparative sections measured on several occasions at Bredon Cloud,* a hill at the north-west of Gloucestershire, at the Cotteswold Hills near Winchcombe, and in the valley of the Evenlode at Stonesfield in Oxfordshire.†

		Bredon Cloud, W.N.W.	Cotteswold Hills.	Stonesfield, E.S.E.
Lias	Upper	380 feet.	200 feet.	10 feet.
	Middle	250 "	150 "	15 "
	Lower	700 "	unknown	unknown.

The positions of the above localities lie in a relative direction from N. N. W. to E. S. E., nearly parallel to that of the attenuation of the Trias, and although the depth of the Lower Lias has not been proved in Oxfordshire, analogy leads us to infer that it thins out in that direction; while upon the same principles we cannot but conclude that all the members of this formation

* Hor. Sec. Geol. Survey, sheet 60.

† "Geology of Woodstock," Mem. Geol. Survey.

originally overspread the plains of Lancashire and Cheshire in great force.*

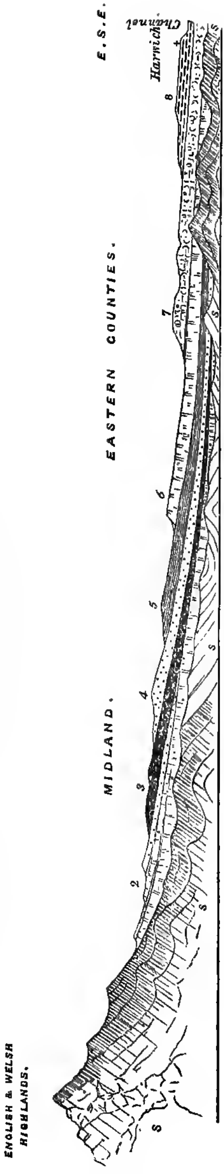
The distribution of the lower Permian strata is somewhat irregular, as they attain a thickness of 1,800 or 2,000 feet in Staffordshire and Warwickshire. Their development in Lancashire is variable.

It is therefore evident that the Coal-measures of the central and north-western counties of England and Wales have been at one time buried beneath an enormous accumulation, amounting to several thousand feet, of lower Mesozoic strata;† but it is still more worthy of observation that this *greatest* vertical development took place over those districts which are occupied by the rich coal-fields of the shires of Derby and York, Lancaster, Flint and Denbigh, Salop and Stafford, subsequently laid bare and rendered accessible by successive denudations. On the other hand, as we have seen, the same post-Carboniferous strata become thinnest in the direction of the Thames valley, over those districts where we believe the Coal-measures have never been formed, and where, if penetrated, we should only reach Cambro-Silurian rocks of à date anterior to the Coal-formation. Thus we see that the marine denudation has been more active and effectual in removing the Secondary strata over those parts of England where they overspread the Coal-formation, than in those districts where they overlie rocks older than, and therefore destitute of, coal.

* Outliers of the Lower Lias occur in Cheshire and Cumberland, the remnants of a once wide-spread formation.

† The terms Mesozoic and Secondary are synonymous.

Fig. 17.—IDEAL TRANSVERSE SECTION OF ENGLAND.
To illustrate the South-easterly attenuation of the Carboniferous, and older Mesozoic Formations, as also the position of the Palæozoic Rocks under the Eastern Counties.



S. Silurian and Cambrian Rocks, forming the foundation for the more recent strata.
2. Lower Carboniferous Rocks.—3. Coal-measures.—4. Trias and Permian.—5. Lias.—6. Oolite.—7. Cretaceous.—8. Tertiary.

The reader will be assisted in the comprehension of this subject by the following ideal section, which (minor details being omitted) is intended to illustrate the past and present distribution of these strata along a band of country stretching from north-west to south-east across Central England. (Fig. 17.)

The original foundation upon which rests the Carboniferous system is shown to be the Silurian and Cambrian rocks, as we find to be the case in Staffordshire and Leicestershire. The Coal-measures are represented by a black band, thickest towards the north-west, becoming thinner and ultimately ending against the older rocks towards the south-east. The overlying formations are also represented, each outcropping in succession towards the north-west, in which direction they become most largely developed, and thinning away towards the south-east. It will be observed that the Coal-formation comes to the surface where it is most productive, and that the overlying formations have been most unsparingly swept away where they have originally been deposited in greatest force.

Now this enormous denudation is a consequence of the upheaval which the formations have experienced at several periods; and as the strata on the whole dip towards the south-east, the elevatory forces have constantly acted with greatest energy in the direction of Wales, Westmoreland, and the north-western counties, also along an axis passing along the Pennine chain, and over the areas of several of the coal-fields; but they have all combined to produce one grand result, namely, the exposure of the Carboniferous rocks towards the north-west of England.

Let us now regard this subject from another point of view. Supposing for a moment that the elevatory forces had acted with greatest energy and effect along the south-east of England so as to produce a general dip towards the north-west, in other words, in a direction opposite to the actual dip of the strata, what, let us inquire, would have been the result?

The answer is obvious, and we can state positively that, to all intents and purposes, England would have been almost as destitute of coal as she would have been had there been no Carboniferous formation. Let the reader glance at the ideal section (p. 258), and then imagine the dip reversed, and the denudation to have taken place *principally* towards the south-eastern side. Two results will at once present themselves. In the first place the old pre-Carboniferous rocks—those of the Cambro-Silurian system—would occupy the right-hand side of the section, and on the left-hand side the Coal-formation would nowhere reach the surface, as it would lie buried beneath an accumulative depth of Secondary rocks: upon it would be piled strata belonging to the Permian, Triassic, Liassic, and Oolitic systems, 6000 to 8000 feet in depth, rendering it inaccessible. Even supposing the elevation of the highlands of England and Wales to have occurred for the most part, as was undoubtedly the case, after the Carboniferous period, these mountains would have been enveloped and probably smothered in the embrace of the post-Carboniferous strata, and the highlands of England would have lain along the region now occupied by the Cretaceous and Tertiary rocks. Under these conditions, Britain would have formed but an appendage of the European Continent. She could not, in all probability, have assumed that insular position which, through the favour of an overruling Providence, has rendered her "a shadow from the heat, a refuge from the storm" to the oppressed of Christendom.

I think, then, it must be evident that there is a happy relationship between the original formation of the rocks and their present distribution; we might even go further, and say that it is highly advantageous, if not the best possible. If the elevatory forces had exerted themselves over the south-east instead of the north-west of England the result would have been disastrous, the former region would have become a mountainous tract, similar to that of Wales, the latter an undulating plain, fitted, indeed, for agriculture, but unproductive of mineral treasures.

The concurrence of events here referred to is the more remarkable as there is no apparent connection between the direction of the elevatory forces and the strata which are influenced by them. Two great series of events, each necessary to give effect to the other, and fraught with the highest temporal blessings to mankind, followed in due course. In a particular portion of our island rich mineral treasures were laid up, but they would never have become available if the internal forces of the earth had taken a direction differing from the reality. As it is, the Carboniferous rocks have been placed within reach over those districts where they are most rich in coal and iron, while that portion of the country where we have reason to believe they were never formed, is mantled over with strata, which, if not peculiarly rich in mineral productions, is profusely stored with the medals of a past creation.

APPENDIX.

A.

Rose Bridge Colliery, near Wigan.

In this colliery two, or rather three, coal-seams are worked. The shaft was originally sunk to the "Pemberton Four-feet" Coal in 1854, and for three years this seam was worked to a considerable extent. In September, 1857, another shaft was commenced at some distance from the former one, to extend from the "Pemberton Four-feet" mine to the "Cannel" and "King" Coals which here lie nearly close together, and which were won on June 30th, 1858. Engine, boiler, and winding machinery were then erected in a chamber hollowed out in the workings of the Pemberton Four-feet Coal, and the trucks from the workings of the Cannel and King Coal, after having been lifted by the underground engine are wheeled along a tramway to the bottom of the upper shaft, through which they are raised to the surface.

The use of two or more lifts or stages produces a loss of time and outlay, but has the advantage of allowing of the working of very deep coal-beds without the risks and dangers always attending such undertakings. It is probable that this means will be generally adopted for working coal-seams from 2000 to 3000, or even 4000 feet in depth.

B.

In 1699, Newcastle had two-thirds of the coal-trade, and 300,000 chaldrons, in all, went annually to London. The over-sea trade employed 900,000 tons of shipping. Coals about that time sold in London for 18*s.* a chaldron, out of which 5*s.* were paid to the king, 1*s.* 6*d.* to St. Paul's, and 1*s.* 6*d.* metage. It was then stated to the House of Commons that 600 ships, one with another of the burden of eighty Newcastle chaldrons, were employing 4,500 men, requisite for carrying on the trade. *Hist. Fossil Fuel*, p. 318.

Æneas Sylvius, afterwards Pope Pius II.

The following is the passage taken from that part of the travels of Æneas Sylvius, relating to Scotland. The account of that kingdom is finished off within the space of one page, which, however, is as much as it had any right to expect, the whole of the British Isles being graphically portrayed by means of three times that quantity of letter-press, and of a sketch-map, which is the more easy of comprehension, as it ignores distance, and is remarkable for simplicity of detail. After dwelling on the scarcity of trees for fuel and other purposes in Scotland at this time (probably the end of the 14th century), he proceeds to describe the following marvellous spectacle, of which he was a witness, "Nam pauperes penè nudos ad templa mendicantes, acceptis lapidibus eleemosynæ gratia datis, lætos abiisse conspeximus; id genus lapidis, sive sulphurea, sive alia pingui materia præditum, pro ligno, quo regio nuda est, comburitur."—*De Scotia:* "Opera," chap. xlvi.

"Ordinatio Vicaræ Ecclesiæ de Merrington." 1343.

"Necnon, et medietatem pecuniæ dedecima mineræ carbonem Willielmi de Het, et heredum suorum." "History of Durham," by R. Surtees, 1828. Appendix, vol. iii. p. 396.

C.

Lighting Mines before the Invention of the Davy Lamp.

There were, however, other means adopted for giving a feeble and uncertain light. The steel mill was the invention most frequently employed in the northern counties; a description and figure of which is given in the "History of Fossil Fuel." By means of a multiplying wheel, a steel periphery was made to revolve rapidly in contact with a piece of flint, by which a succession of sparks was produced. The sparks, being formed of minute particles of steel heated to redness, are incapable of igniting the explosive gases of the mine, though sufficiently bright to light dimly the workings. In those mines where carburetted hydrogen gas existed in minute quantities, naked candles were employed for lighting, and gunpowder for blasting.

D.

The following explanation of the terms here used, as given by Sir C. Lyell, may be of service to those unfamiliar with botanical nomenclature, especially in its application to palæontology.

	Brongniart.	*Lindley.*	
Cryptogamic.	1 Cryptogamous amphigens, or cellular cryptogamic.	Thallogens.	Lichens, sea-weeds, fungi.
	2 Cryptogamous acrogens.	Acrogens.	Mosses, equisetums, ferns, lycopodiums, — (Lepidodendron Sigillaria? calamites, &c.)
Phanerogamic.	3 Dicotyledonous gymnosperms.	Gymnogens.	Conifers and Cycads.
	4 Dicot. Angiosperms.	Exogens.	Compositæ, leguminosæ, umbelliferæ, cruciferæ, rosaceæ, forest trees, &c. Probably no representatives in the Carboniferous flora.
	5 Monocotyledons.	Endogens.	Palms, lilies, aloes, rushes, grasses.

E.

Coal-mining in China.

Marco Polo, who travelled through China towards the close of the 13th century, mentions coal as one of the commodities in use in his time in that country. At the present day, it is worked in the cliffs of the Pe-Kiang river at Tingtih, by means of adits driven into the side of the hill at the outcrop of the coal-seams. The works are carried on in the most primitive manner, without the aid of machinery, and the mode of working coal through vertical shafts, which may be considered, as the second stage in the art of mining, appears little known. In this respect, as in almost every other, the Chinese are far behind their neighbours the Japanese. Probably, if an inhabitant of the celestial empire were shown some of the largest collieries of Newcastle, or Wigan, he would scarcely deign to look at them, or would gravely inform you that they have similar, or better machinery, and deeper mines "Pekin side."

Mr. Oliphant states that coal is procured from a mine about five miles distant from the important city of Whang-shih-kang, or "Yellow Stone," on the river Yang-tse-kiang, situated about 400 miles from its mouth.—"Narrative of Lord Elgin's Mission to China and Japan," vol. ii. p. 389.

F.

Coal-mining—Japan.

Mr. Oliphant states that coal is raised in Japan somewhat extensively—but as a Government monopoly. One mine, at a place called Wuku Moto, in the interior of the main island of Niphon, was visited by some of the Dutch Mission. They describe the mine as being well and judiciously worked, and the coal as bituminous in its nature, and made into coke for use.

That the coal is worked by means of vertical shafts appears from the fact that the Prince of Fizen once ordered a steam-engine from Europe for pumping the water out of his mines; but, through the native jealousy of the presence of foreigners in the country, refused to allow the Dutch engineer to erect the machinery upon the spot. The Japanese, however, are quite independent of European aid for such an object, as they thoroughly understand the construction and management of the steam-engine.—"Lord Elgin's Mission to China and Japan," vol. ii.

Kæmpfer, in his "History of Japan," also refers to the abundance of this mineral—stating that it is dug in great quantity in the province of Tsekusen, and in most of the northern provinces. This rich and productive empire also yields abundance of gold, silver, copper, and iron; and the Japanese armourers excel the Europeans, and perhaps any other nation, in tempering steel.

G.

Mr. Fordyce in his "History of Coal, Coke, and Coal-fields, 1860," gives the following account of the calculations which have been made regarding the duration of the Great Northern Coal-field of Durham and Northumberland. He says: "The most able mining engineers have based their calculations upon the various workable coal-seams, and upon the consumption of coal at the time of their inquiry; hence different results have been arrived at without there being any material difference of opinion as to the quantity of coal yet unworked. Mr. Hugh Taylor, in his evidence before a Select Committee of the House of Lords, in 1829, based his calculations upon the consumption of coal at 3,500,000 tons per annum, and therefore estimated the duration of the Northern Coal-field at 1727 years. This opinion has been adopted by various subsequent writers who, it would appear, have overlooked the annually increasing demand for the coal of the district. Were Mr. Hugh Taylor giving an opinion at the present time, with a consumption of about 17 million tons per annum, instead of 3,500,000, it would only prove his statement to be pretty nearly correct as to the quantity of workable coal in the counties of Durham and Northumberland. Mr. Greenwell states that 'the Northern Coal-field would continue 331 years;' his estimates were made in 1846, at which time he gives the consumption of coal at the rate of upwards of 10 millions of tons per annum. Mr. T. Y. Hall, in

1854, referring to the estimates of Mr. Taylor and Mr. Greenwell, states, 'that various methods of calculations by sections of different districts have been tried both by Mr. Greenwell and myself, unknown to each other, and the results, which it was impossible to anticipate, have been found to be perfectly similar as regards quantity.' Mr. Hall, in 1854, takes the annual consumption of coal at 14 millions of tons, including the small coal as saleable, and gives 365 years as the period at which this coal-field will be exhausted. He estimates the total quantity of coal that may be workable under the area of

750 square miles at . . .	8,182,805,757	tons.
Deducting for loss and waste .	1,608,561,151	„
Ditto for quantity already extracted	898,812,433	„
Ditto for casualties, &c. .	553,543,217	„
Leaving for future use . .	5,121,888,956	„

This quantity divided by 14 millions, annually extracted for sales and pit consumption, gives 365 years. But from the great annual increase in the demand for coal from this portion of the coal-field of Great Britain, Mr. Hall assumes that the consumption is not unlikely, before many years elapse, to reach not less than 20 millions of tons annually. Supposing that this quantity should be required, then, at that rate of demand, the coal-field would be exhausted in the course of 256 years."

Mr. Fordyce appears to concur in these calculations of Mr. Hall; for myself, I am ready to accept results which have been arrived at on independent grounds by persons so well acquainted with the district as the authors above named. My own calculations of the resources and the length of time necessary for their exhaustion is somewhat greater, arising, principally, from a smaller deduction for waste and loss than that assumed by Mr. Hall.

H.

Boring at Harwich.

The following are the particulars of this interesting trial in search of water:—

Drift	25	feet.
Tertiary Strata	51½	"
Chalk	888	"
Greensand and Gault	61	"
Black Slaty Rock	44½	"
	1070	"

Mr. Prestwich is evidently inclined to refer the slate to the Silurian period. Its cleaved character, the absence of lime, and the trace of one fossil shell—apparently a large *Posidonia*—seem to corroborate this view.

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